AN INVESTIGATION

OF

CYCLONIC PHENOMENA

IN

NEW ENGLAND.

By WINSLOW UPTON.

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OF

CYCLONIC PHENOMENA IN NEW ENGLAND.

By WINSLOW UPTON, Providence, Rhode Island.

The local weather services of the United States are rapidly collecting from their numerous observers a mass of material which can be made the bases of valuable researches. The U. S. Signal Service, with its stations scattered over the whole country, investigates meteorological phenomena on a large scale, taking a comprehensive but necessarily general survey of the field. The local services, which may have a larger number of observers in a single State than the general service has in all the States of the Union, are in a position to supplement the work of the government by filling in the minute details of its investigations. The New England Meteorological Society acts as the local weather service for New England, and desires not merely to collect and tabulate meteorological observations, but to use the material thus obtained for subsequent study. The data collected by this society relate primarily to precipitation and temperature, but little attention having been directed to other subjects; the observations of the former include not only amounts and character, whether rain or snow, but also the times of beginning and ending of the precipitation, while a clear separation is maintained between the records of rain and snow, on account of the difficulty and oftentimes the impossibility of measuring the latter with accuracy. As the work of the society

is wholly voluntary, it is not possible to secure complete returns from all observers, but a large number of the observers are careful to record all that is asked, and to observe on the uniform plan recommended. The distribution of the observing stations is necessarily uneven, from a geographical standpoint, but the closeness of the stations in eastern Massachusetts is an advantage for minute study over this limited area. The Bulletin of the Society for July, 1886, embraced reports from 151 observers, distributed as follows: 14 in Maine, principally in the southwestern portion of the state, 21 in New Hampshire, 14 in Vermont, 68 in Massachusetts, 9 in Rhode Island, 15 in Connecticut, 8 in New York east of the Hudson and 2 in New Brunswick.

The investigation described in this paper is an attempt to make use of the material collected by the observers in New England as far as it relates to precipitation, especially to determine the peculiarities of its distribution in the separate storm movements. It covers the period from January, 1885, when the Society had just entered upon its work and for which month 80 reports were received, through July, 1886, when the number of reports had nearly doubled. A grateful acknowledgment is made to the trustees of the Elizabeth Thompson Science Fund for a grant, which has been devoted principally to the payment of the clerical assistance necessaay for discussing so large an accumulation of material, and without which the investigation would not have been made. Much assistance has also been received from the U. S. Signal Service, whose daily weather maps and monthly Weather Review has been freely used, and whose observers in New England make regular reports to the Society. Special data not included in the regular reports have also been kindly furnished on several occasions by both voluntary observers of the Society and by the U. S. Signal Service.

The cyclones, whose passage over or near New England influence the prevailing weather conditions, are of very frequent occurrence. The word *cyclone* is here used, not as the synonym of tornado or hurricane—its frequent use in the daily press—but as the general name for storm movements which are charac-

terized by a centre of diminished pressure toward which the surface winds blow, circulating about the centre as they approach it in a direction contrary to the motion of clock hands. These storm movements may be classified into two general groups, (1) those which approach from the Great Lakes on the west, (2) those which approach from the south or southwest. The storms of the former class are the more numerous while those of the latter are in general more severe in the violence of the winds and and the amount of precipitation noted in New England. The former usually enter the country in the extreme northwest, move easterly over the Lakes and northwesterly down the St. Lawrence valley, north of New England. Not infrequently they move directly across New England from the Lakes to the Atlantic, instead of continuing down the St. Lawrence valley. Sometimes their origin is in the southwest and sometimes they enter the country from the Gulf of Mexico, proceeding northerly or northeasterly to the Lakes and thence approaching New England from the west. Occasionally, during the passage of a cyclone from the Lakes, a secondary development is formed in the Atlantic south of New England, which moves northerly until the two unite; or a cyclone from the west may unite with one from the south, both approaching New England at the same time. The storms of the second group in their complete form, are the cyclones known as the West Indian hurricanes, which approach the United States in a northwesterly direction from equatorial regions, curve to the northeast in or near the Gulf of Mexico and move up the Atlantic coast, sometimes within the above line, sometimes wholly in the ocean. Frequently the cyclones of this group are developed in this country, north of the Gulf of Mexico or in the southern states, and occasionally one approaches the New England coast from the Atlantic ocean, not having been earlier observed.

Of the cyclones of these two classes which had a prominent influence on New England weather in the nineteen months, January, 1885–July 1886, forty-one have been studied, embracing those which actually crossed New England or which passed sufficiently near to show a marked effect upon its meteorological

conditions. These will be treated in three divisions: (I) those of the first class mentioned above, numbering twenty-two, (II) those of the second class numbering thirteen, (III) special cyclones in which a secondary development was formed on the Atlantic coast and in which two cyclones united, numbering six. The method of study has been: first to tabulate the data furnished by observers, and then to chart them upon maps of New England made upon a scale of thirty miles to the inch. These maps had been specially prepared for the purpose by the cyclostile process, and contained the position of each observing station carefully located. Further tabulations and charts were made, as suggested in the course of the work, which will be mentioned below. The authority for the storm tracks is the United States Signal Service, the tracks having been copied from the monthly Western Review or the Daily Map of the Service.

I. CYCLONES APPROACHING NEW ENGLAND FROM THE WEST.

These may be considered in sub-divisions, (*a*) those which actually moved across New England, numbering fourteen of the twenty-two, (*b*) those which moved just beyond the boundary,—the remaining eight; of the latter seven moved north of the boundary and one south. The following table gives in condensed form the general characteristics of each storm, preliminary to a more detailed discussion. In the column headed "date of passage" is given the date at which the centre of each depression was over New England, or passed at its nearest point to the district. The letters *d* or *i* following the barometric pressures indicate that the pressure was either diminishing or increasing as the storm moved along; in the former case the cyclone was gaining, in the latter losing in energy. Where neither of these letters is appended, the cyclone was moving without marked increase or decrease in its violence. The column containing maximum amount of precipitation gives not the highest single record, but generally the average of the three highest, as the design is to show the rainfall over a considerable area; in a few cases abnormally large records at individual sta-

tions, much exceeding those in the vicinity, have not been included for the same reason. The time of duration of the precipitation is reckoned from the stations in eastern Massachusetts only. The blanks in the table are explained in the current description of each storm.

TABLE I.—General characteristics of Cyclones.

A. Cyclones which moved from the west *across* New England.

Reference No.	Date of passage.	Pressure at centre. (inches)	Hourly Velocity. (Miles.)	PRECIPITATION.		
				Kind.	Max. am't. (inches.)	Duration. (Hours.)
1	...Jan. 17, 1885....	29.1 *d*	40	Rain & Snow.	2.0	48
2	...Feb. 1, 1885.....	29.4 *d*	32	Snow.	1.0	9
3	...Feb. 4. 1885.....	29.3	35	Snow.	0 2	17
4	...Mar. 10, 1885....	29.4	46	Snow.	0.4	4
5	...April 13, 1885...	—— *t*	—	Rain & Snow.	0.3	—
6	...April 29, 1885...	29.2 *d*	20	Rain.	1 6	26
7	...June 29, 1885...	29.7	13	Rain.	3 3	48
8	...Sept. 9, 1885....	29.6	21	Rain.	1.9	35
9	...Nov 19, 1885....	29.6 *d*	31	Rain.	0.9	7
10	...Dec. 19, 188	29.3 *d*	21	Snow.	—	—
11	...Jan. 5, 1886.....	29.4 *d*	30	Rain & Snow.	2 5	—
12	...Feb. 20, 1886.....	29.1 *d*	40	Rain & Snow.	1.2	—
13	...Feb. 26, 1886.....	29 0 *d*	42	Rain & Snow.	2.7	30
14	...Mar. 9, 1886.....	29.7	42	Rain & Snow.	0.7	16
	B. Cyclones which moved from the west *near* New England.					
15	...Mar. 25, 1885....	29.8	36	Snow.	—	—
16	...June 5, 1885.....	29.6 *t*	—	Rain.	1.9	—
17	...July 10, 1885.....	29.6	20	Rain.	2 2	—
18	...Aug. 4, 1885.....	29.5 *t*	30	Rain.	5.4	16
19	.. Aug. 22, 1885.....	29.6	47	Rain.	1.9	—
20	...Oct. 14, 1885.....	29.4 *t*	19	Rain.	3.2	26
21	...June 3, 1886.....	29.5 *d*	31	Rain.	1.0	6
22	...July 16, 1886....	29.7	—	Rain.	5.1	—

In order to show graphically the paths followed by the cyclones which traversed New England, the accompanying chart has been drawn (Chart I.). It contains that part of New England in which all but a few of the reporting stations are located. Each track bears the number assigned to the cyclone in Table I. This chart also contains the tracks of the cyclones which crossed New England from the south, drawn in broken lines, for future reference. It will be noticed that the paths of the cyclones now under discussion fall into two distinct groups, one in the north, Nos. 1, 2, 3, 4, 10, 11, 12 and 13; and one in the south, Nos. 6, 8, 9 and 14. The track of No. 5 cannot be drawn, as the cyclone lost its definite form near the western boundary, and became dissipated over New England. No. 7 moved in an abnormal path: on reaching Massachusetts Bay it remained nearly stationary for a day, when it developed sufficient energy to resume its journey, and passed a second time over the district. The

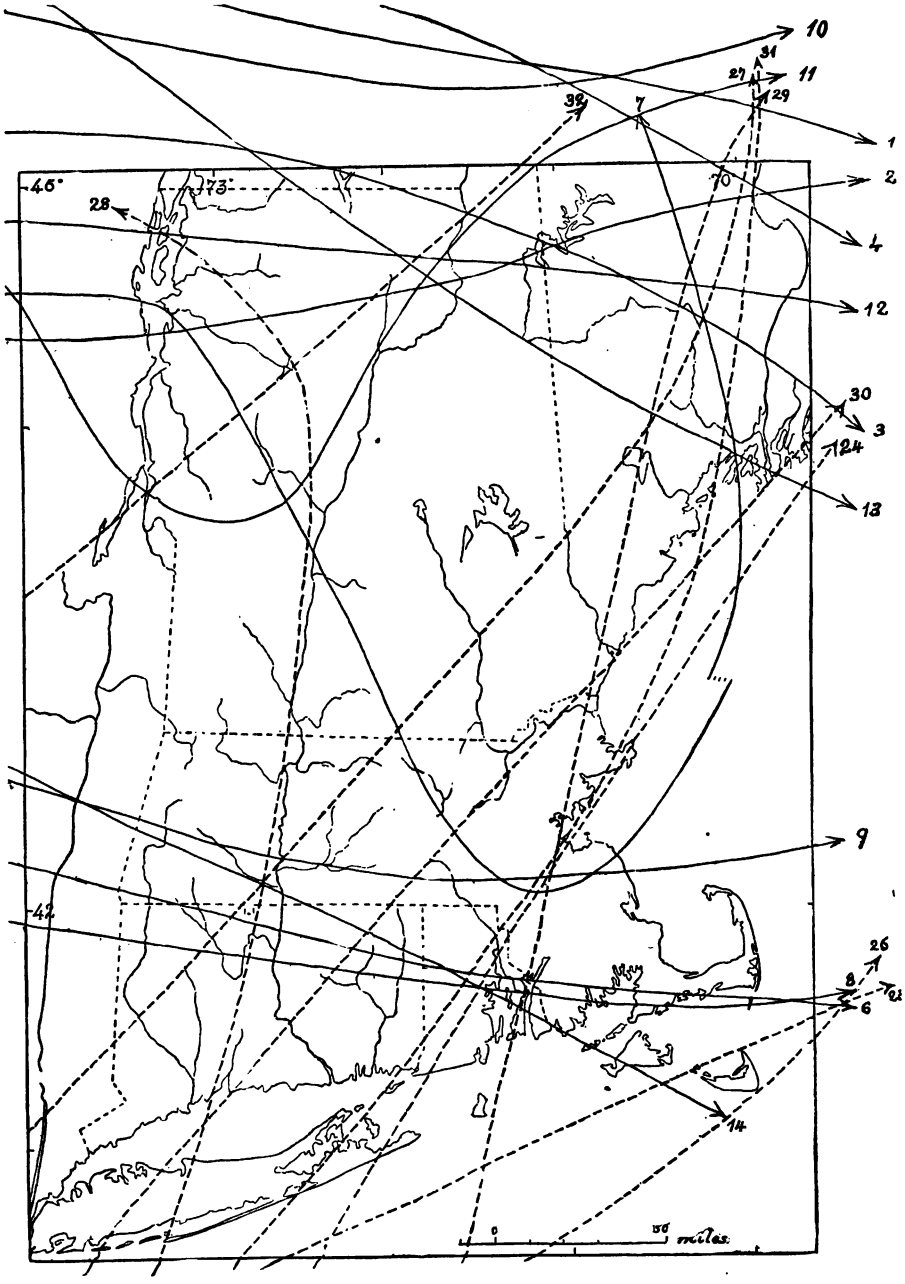

CHART I.—*Paths of Cyclones across New England.*

Full lines indicate cyclones approaching from the west; dotted lines those approaching from the south. The numbers are the current numbers in Tables I. and V.

description of the individual storms should be read with constant reference to this chart and the data given in Table I.

A brief account of the characteristics of each of these cyclones will now be given.*

1. Jan. 17, 1885.—This was a very severe storm which moved from Texas to the Lakes, thence across New England and the Atlantic Ocean to the Irish coast, which it reached on the fifth day after leaving the United States. The pressure diminished from 29.9 to 29.0 as it moved over the land. The precipitation was heavy, rain and snow mixed, and the the maximum area lay over Massachusetts, Rhode Island and Connecticut.

2. Feb. 1, 1885.—This was a moderate snow storm which entered the country in the northwest; after leaving the coast, it united with a severe cyclone which was moving in the Atlantic, and which reached the New England coast five days later. The snow was light, the maximum of 10 inches having been noticed in northern Vermont, and the southern coast marking the limit of the precipitation.

3. Feb. 4, 1885.—There was also a light snow-storm moving in this country in a path similar to the preceding, and not known to have advanced far in the Atlantic. The distribution of the precipitation cannot be made out on account of the smallness of the snowfall, but was probably at its maximum in New Hampshire and Vermont.

4. March 10, 1885.—This cyclone moved in a path somewhat similar to the two preceding, but farther north. The precipitation was light snow, having its maximum of 4 inches in the north, and hardly noticed in the southern portion. The southern limit was probably near the coast, or about 300 miles from the central path.

5. April 13, 1885.—This cyclone approached from the Lakes on the 12th, with a central pressure of 29.6 inches, but dissipated over New England on the following day. The precipitation was light rain, with some snow; it began on the 12th, and continued in the form of occasional showers for two days. The

*The adjectives "severe" or "violent," when applied to storms, refer to the force of the wind and not to the character of the rain and snow.

maximum precipitation was in Southern Vermont, and secondary maxima also occurred along the Merrimac river and in southeastern Connecticut. The least precipitation (which was of trifling amount) was noted in the extreme north and in western Connecticut.

6. April 29, 1885.—This cyclone approached from Colorado, and disappeared in the Atlantic. As it passed over southeastern Massachusetts it was retarded, the velocity diminishing from 30 to 10 miles per hour. This retardation produced a similar tarrying in the duration of the rain; the time of ending of the rain on the eastern coast of Massachusetts having been nearly twelve hours later than at the Connecticut river. The heaviest rains occurred in northeastern Massachusetts.

7. June 29, 1885.—This cyclone moved in a peculiar path, and had marked characteristics. It moved from Lake Superior, crossing New England, on June 29th, in a southeasterly direction, but curving sharply to the northeast as it entered Massachusetts Bay. For about twenty-four hours it remained nearly stationary, when it again moved, and crossed western Maine in a northerly direction on July 1st; it again lost its energy, and after existing for two days as a depression without a clearly defined centre, it was dissipated. The precipitation was heavy rain, with maxima exceeding 2 inches in eastern Massachusetts, northern Vermont and, especially, in southwestern Maine, where amounts of 4 inches and upwards were recorded. The fewness of the stations in Maine makes it impossible to determine the distribution in that state. The amount is clearly connected with the tarrying of the storm and its abnormal path. The rain came in a succession of showers which prevailed between June 28th and July 2d.*

8. Sept. 9, 1885.—This cyclone advanced from Colorado (probably having come from the Pacific Coast), and after leaving the United States moved in four days across the ocean to the British coast. It was not a severe storm, and the rainfall was less than

* See "Thunder-Storms in New England in the Summer of 1885," by Prof. W. M. Davis, in Proc. Amer. Acad., July, 1886.

one inch except in the northern part of New England, where it reached two inches.

9. Nov. 19, 1885.—This storm, which came from Dakota, also traveled across the Atlantic, passing from shore to shore in five days. As it crossed New England it was attended by light rains, which were heaviest in northern New Hampshire and Vermont. A marked peculiarity of the precipitation is that in eastern Massachusetts, near the path of the central depression, the rain did not begin until about five hours *after* the center had passed, its distance being about 130 miles eastward.

10. Dec. 19, 1885.—This cyclone traveled from the northwest, possibly having crossed the Rocky Mountains from the Pacific coast, and passed into the Atlantic. It was increasing in severity as it approached the coast, and the precipitation was in the form of snow. It has been found impossible to separate the records of snowfall belonging to this storm from those of several days immediately preceding, and therefore its distribution cannot be determined.

11. Jan. 5, 1886.—This cyclone formed in Texas, moved to the Lakes, thence over New England and to the Gulf of St. Lawrence, as a storm of great severity. The winds were high, but exceeded by those in the storm which followed four days later, and which was developed under the same conditions. This second storm will be especially treated in a subsequent section. The peculiar curve in the path of this storm is probably due to the development of a second centre on the morning of the 5th southwest of New England, which drew towards it the centre at that time over the Lake region. The rain and snow were heavy, showing maximum areas in western Connecticut and southwestern Maine. The times of beginning were, however, so varied that the duration of the snowfall cannot be accurately given.

12. Feb. 20, 1886.—This was a severe storm which came from the northwest, and has been traced nearly across the Atlantic. As it crossed New England, rain and snow fell, which reached their maximum in southwestern Maine. The storm ended in light snows at various times, rendering the determination of its duration uncertain.

13. Feb. 26, 1886.—This was one of the most violent storms on record as far as relates to the severity of the winds and their long continuance. It came from the northwest, and passed into the ocean with increasing energy. The high pressures which followed closely after, caused such a deep gradient that the winds were of unwonted violence, and the maintenance of this gradient for several days, while the storm centre remained nearly stationary in the Atlantic, caused their long continuance. The intense cold following the storm gave additional discomfort to the severity of the winds. The temperature was mild preceding the storm, and the form of the precipitation was rain and snow. It was large in amount, giving maxima exceeding two inches in southwestern Maine and southern Connecticut.

14. March 9, 1886.—This was not a severe storm. It came from the northwest, and has been traced to the Irish coast, It moved rapidly in this country, and was five days in crossing the ocean. Light rain and snow attended its passage, and were heaviest in southwestern Maine, and lightest in Massachusetts near the central path of the cyclone.

15. Mar. 25, 1885.—This storm came from the northwest and moved northeasterly about 170 miles north of the northern boundary of Vermont. It was attended by snows which in New England were not general. Probably the southern limit of the general precipitation was near the Vermont boundary. The sixteen stations reporting light snows are situated: seven on the coast, two in Connecticut near the coast, two in the mountains of Vermont, one in central New Hampshire, two in the Berkshire range, one in eastern New York, and one in Vermont near the northern boundary.

16. June 5, 1885.—This cyclone approached from Colorado, but curved to the southeast before reaching New England, and entered the ocean from northern New Jersey. The rains were heavy on the 5th, with light showers preceding, and were most abundant in northern Massachusetts, southern New Hampshire and Vermont.

17. July 10, 1885.—This well-developed cyclone passed 160 miles north of the Vermont and Canada boundary, on its north-

eastward path from Montana. It was attended by a series of showers which were especially severe on the 9th (see Prof. Davis' discussion referred to above). The rainfall between the 7th and 10th has maxima exceeding two inches in northern Vermont and in Rhode Island.

18. Aug. 4, 1885.—This cyclone came from Arkansas and moved northeasterly, passing 230 miles north of the northern boundary of Vermont. It was attended by remarkably heavy rains and thunder-showers on the 3d–5th, the principal amount falling on the 4th. The stations reporting more than five inches of rain are in southwestern Connecticut and central Massachusetts. The least rainfall was in the extreme northwestern corner of Vermont and the opposite southeastern corner of Massachusetts where the amounts were about 0.8 and 0.2 inches respectively. A trough of heavy rainfall exceeding two inches extended from southwest to northeast from 30 to 100 miles wide, and is parallel with the storm track, at a distance from it of about 300 miles.

This cyclone has been selected to illustrate the varied distribution of the precipitation in all the storms under discussion. (Chart II.) It is not peculiar in this respect, though few of the cyclones exhibit the parallelism in the region of heaviest precipitation to the path of the cyclone which is here shown. All, however, show that the amount of precipitation is not gradually progressive from the path of the cyclone outwards but is distributed unevenly, with clearly defined areas of maximum and minimum precipitation.

19. Aug. 22, 1885.—This cyclone entered the country in Minnesota and moved 200 miles north of Vermont in a northeasterly direction. Thunder-storms occurred on the 22d north of Rhode Island and Connecticut with abundant rains, especially in the Hudson valley at Albany. Local showers also occurred on the 21st.

20. Oct. 14, 1885.—This storm came from the West Indies, entered the country on the Florida coast, moved to the Lakes and then curved to the northeast. It passed 60 miles north of Vermont and crossed the extreme northern portion of Maine.

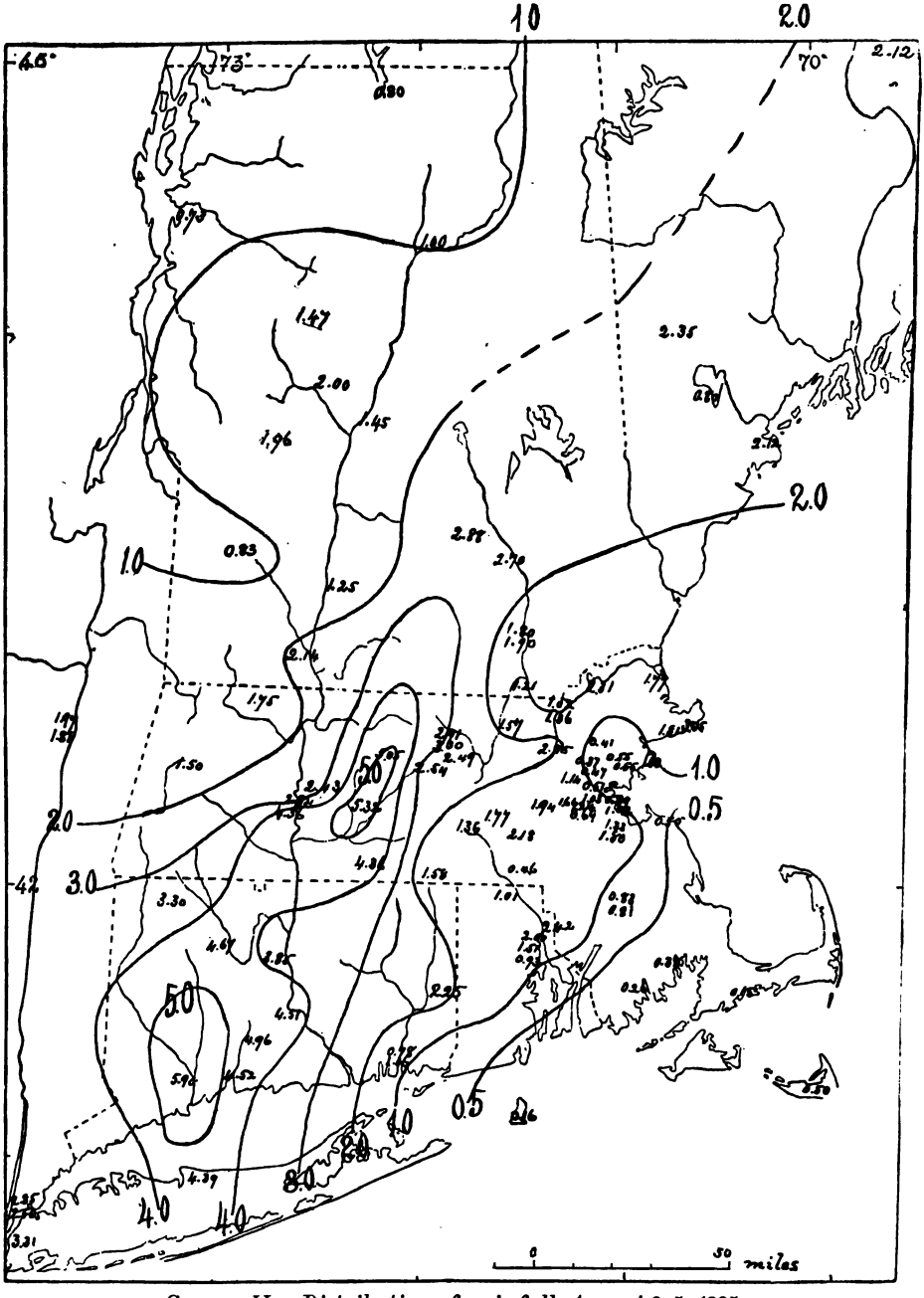

CHART II.—*Distribution of rainfall, August 3–5, 1885.*

The rainfall is given in inches; the full lines are lines of equal rainfall, drawn for every half-inch.

The rains were excessive, over two inches having fallen in northern Rhode Island, and northeastern Massachusetts. The smallest amounts were at the stations in northern Vermont nearest the storm-path, and were less than 0.2 inch.

21. June 3, 1886.—This well-developed cyclone came from Kansas and passed our district 200 miles north of Vermont, moving northeasterly. The rains were light and show maxima of 1.0 inch in the Hudson valley and on the Maine coast and of 0.7 inch in northern Vermont. The rainfall did not begin until the storm centre had passed beyond its nearest position to the district.

22. July 16, 1886.—The path of this cyclone cannot be defined with the data at hand at the time of writing, but it moved from the Lakes northeasterly, far north of New England. The rains were heavy on the 14th and 15th, with a continuation of showers on the 16th and severe thunder-showers on the 18th. The amount between the 14th and 18th exceeded five inches at Setauket, Long Island, and exceeded three inches in the large area containing the state of Connecticut west of the Willimantic and Thames rivers, with a portion of southern Massachusetts and eastern New York. But little rain fell in southeastern Massachusetts.

The foregoing description has been confined to a brief statement of the path of each cyclone, and a general statement regarding its precipitation. Further attention will now be given to the latter, for the study of which the principal data available are its amount, and the times of beginning and ending in each storm. There are many subjects which may be studied with the help of this material, such as the manner in which the precipitation is distributed in relation to the path of the cyclone, and its relation to the physical features of New England. It may be asked, too, whether each storm is peculiarly individual in its characteristics, a law to itself, or whether there are indications of general laws of distribution. The subjects of the rate of progression of the front and rear of the precipitation and its direction, compared with those of the storm centre, are also

worthy of investigation. The difficulties in the way are the unavoidable uncertainty attending the data. The rain guages are not of uniform accuracy and their exposure is varied; the danger from these causes has been reduced to its minimum by the special exertions which have been made to promote uniformity among the observers whose reports are accepted by the Society, but in a voluntary system this is only possible to a limited degree. A further difficulty arises from the great range in the readings of the best gauges at stations only a short distance apart which must always necessitate caution in drawing generalizations from their records. There are also inherent difficulties in the records of the times of beginning and ending of precipitation. Oftentimes precipitation begins with light rains or snows occurring at irregular intervals, and the exact time to be noted is not apparent; a similar difficulty attends the cessation of the rain and snow. The times noted are therefore quite uncertain because the phenomena themselves may be incapable

TABLE II. Relation of the precipitation to the path of the cyclone.

No.	Distance of max. area fr'm path. (miles).	Direction of max. area from path.	Distance of centre at begin. of prec'n. (miles.)	No. of Records.	Direct'n of centre at begin. of precipitation.	Distance of centre at end of prec'n. (miles.)	No. of Records.	Direct'n of centre at end of precipitation.
1	250	S S W	1352 †	36	S W	243	27	N
2	20 ?	N ?	281	32	N W	189	30	N E
3	140	S W	326	20	N W	———	—	———
4	80 ?	S W ?	341	14	N W	———	—	———
5	———	———	250	16	N W	———	—	———
6	60	N N E	144	36	W	220 *	15	E
7	———	———	380	29	N W	———	—	———
8	180	N W	785	46	W	———	—	———
9	180	N W	130 –	20	E	326	49	E
11	190	S W	———	—	———	364	20	N W
12	50	S	379	58	N W	288	11	N W
13	30	N E	557	70	N W	———	—	———
14	160	N E	444	47	W	200 *	23	S E
16	240	N	——–	—	———	20 *	13	S W
17	220	S E	350	18	N	———	—	———
18	430	S E	394	49	W	403	23	N
19	310	S E	367	16	N W	———	—	———
20	250	S S E	662	58	W	327	45	N W
21	320	S E	600	31	N N E	700	26	N N E
Av'ge Nos,								
1, 2, 3, 4, 11, 12, 13.....	94	S	377 ‡			271		
6, 8, 9, 14.....	145	N	376			249		
17, 18, 19, 20, 21.....	306	S E	475			477		

† Distances thus marked were determined from stations in eastern Massachusetts only. Precipitation began while the cyclone was developing in the southwest.

‡ Omitting Number 1.

of exact determination. In summer thunder-storms, the rain begins as a rule with such definiteness that the time can be sharply determined, but in the general rains of a year this is not always the case.

The results of the study of the precipitation data may be indicated without a minute description of the details of the investigation. Tabulation and simple charting on maps of New England have been the means employed. Table II contains a summary of the facts obtained relating to the location of the area of greatest precipitation, and the distance and direction of the storm centre when the rain or snow began and ceased. The omissions are due to lack of sufficient data in certain instances to give results of value. A comparison of the values given in this table with the storm tracks pictured in Chart I, and with the brief descriptions of the storms, will throw much light upon their characteristics.

Attention has already been drawn to the fact that the storm tracks, illustrated in Chart I., fell into two distinct groups; those which cross New England in the north (Nos. 1, 2, 3, 4, 10, 11, 12 and 13) and those which cross in the south (Nos. 6, 8, 9 and 14). In the group whose paths lie outside of New England, all except No. 16 passed north of the States in Canada. The averages appended to the table have been derived for each of these groups; it should be noticed, however, that the ranges are large and as the number of storms in each group is small, the numerical averages must be regarded as only a rough indication of the true averages of a large number of similar storms. Comparing the values of the distance of the centre when rain or snow began with the values of the amounts of precipitation in Table I., it will be seen that in general the greater the distance of the centre the larger is the precipitation, but this is not invariably the case, as in Nos. 1 and 20 compared with Nos. 13 and 18 respectively. Summer showers which may not begin until the storm centre is at its nearest point, or has even passed beyond it, often give more rain than accompanies other cyclones when the rain begins earlier and continues longer.

Before specifying the results obtained from Table II, (See page 264, October No.) two other tables are presented which contain the results of a further investigation upon the times of beginning and ending of precipitation, in order to group together the conclusions of this section. These tables are designed to show the progression of the front of the precipitation and also of its rear, within the limits of observation. The data are more meagre for this investigation than for the preceding, for it requires time observations made not only at a given group of stations, but all along the district. As it usually, for example, begins to rain about eight hours later in eastern Massachusetts than at the western boundary of the state, when the progression is easterly, it often happens that observations at one extremity are in the night. This added to the inherent difficulty of all observations of the time of beginning and ending of precipitation is the cause of the omission from the tables of some storms altogether, and numerous omissions in those that are included. The headings of these tables may need some explanation. The phrase "Geographical Area" denotes that portion of New England over which the observations are sufficiently abundant to be used for this purpose. On the maps containing these records, lines were drawn showing the places where it began (or ceased) to rain or snow at the same time; the advance of these lines furnishes the means of calculating the rates given in the sixth column of each table. The "Interval in Hours" is the time elapsed between the earliest and latest of these isochronous lines. Thus in table III, No. 2, the data are confined to the state of Massachusetts, and the direction of progression was easterly. It began to snow near the western boundary five hours before it began to snow near the eastern, and the rate was about nineteen miles per hour. Columns four and seven give data for the movement of the centre of the cyclone corresponding to those given in the preceding columns for the precipitation front or rear, for purposes of comparison. The last two columns give the interval between the times of beginning or ending of precipitation and the arrival of the centre of the cyclone at its nearest point. It is twice reckoned; (a) from the earliest (b) from

the latest of the lines of equal time. The difference in these two values is due to a difference in the rate of movement of the centre of the cyclone and the boundary lines of its precipitation. This may be due either to a widening or contracting of the precipitation area of the cyclone or to a change of rate of the cyclone after the precipitation had begun (or before it had ceased) and the time of its passage. The values of the rate of the cyclone and its direction are calculated for its position when the rain or snow was beginning (or ceasing) and, therefore, differ from those previously given in Table I and Chart I. In order further to illustrate this subject, Chart III is given, which represents the progression of the time of beginning of rain on Oct. 13, 1885, storm No. 20. Similar charts for Nos. 7 and 17 are given by Prof. Davis in his paper on Thunderstorms of 1885, above referred to.

TABLE III.

Relation of the time of begininng of the precipitation to the position of the centre of the cyclone.

No.	Geographical Area.	Direction of motion of prec. front.	Direction of motion of cyclone.	Interval in hours.	Hourly rate prec. front. (miles)	Hourly rate of cyclone. (miles)	Interval before arrival of cyclone.	
							a (hours)	b (hours)
1	Conn., Mass, R. I.	N. E.	N. E.	3	56	20	42§	43§
2	Mass.	E.	E.	5	19	41	9	6
3	Eastern Mass.	.....	E.	.....	.....	26	11	....
5	Eastern Mass.	....	E.	.....	.....	.....	.....	.....
6	....	N.?	E. S. E.	.....	.....	30	.....	.....
7	Eastern Mass.	.....	E.	.....	.....	22	15	.....
8	Vt, Conn., Mass., R. I.	E.	E.	7	34	24	20	23
9	Eastern Mass.	.....	E. N. E.	... .	.....	24	-5*	....
12	Whole area.	N. N.E.	N. E.	8	38	28	13	8
13	Eastern Mass.	.....	E.	.....	.....	29	17	.....
14	Eastern Mass.	E.?	E.	.....	.....	33	10	.....
17†	Vt.. Mass.	S. E.	N. E.	4	28	18	0	0
18	Whole area exc. Me.	N. E.	N. E.	12	15	25	26	20
19‡	Whole area.	S. E.	N. E.	23	11	36	5	.....
20	Whole area	N. E.	N. W.	13	24	18	32	30
21	Eastern Mass	S. E.	N E.	.....	.....	28	-12*	... .

* The negative sign indicates that the centre had passed *before* the precipitation began.

† Reference is to the rain of July 9, 1885; there had been earlier showers.

‡ Reference is to the rain of Aug. 22, 1885; it had rained on the preceding day, the motion of the rain front having been easterly.

§ Precipitation began while the cyclone was developing in the south-west.

TABLE IV.

Relation of the time of ending of the precipitation to the position of the centre of the cyclone.

No.	Geographical Area.	Direction of motion of prec. rear.	Direction of motion of cyclone.	Interval in hours.	Hourly rate of prec. rear. (miles)	Hourly rate of cyclone. (miles)	Interval after passage of cyclone. a. (hours)	Interval after passage of cyclone. b. (hours)
1	Conn., Mass.	N. E.	E.	4	35	40	-2*	-1*
6	Vt., Mass.	S E.	E.	14	11	15	12	17
9	Vt., Mass., Conn., Me.	S. E.	E.	12	8	24	3	12
11	Mass., Conn., R. I.	E.	S. E.	10	10	38	-15*	-13*
14	Eastern Mass.	....	E	.....	.....	27	5	.....
16	Eastern Mass.	E.	S. E.	.....	.....	9	.....	.....
18	Eastern Mass.	N. E.†	N. E.	.....	.....	28	-4*	....
20	Eastern Mass.	N. E‡	N. E.	....	.....	35	8	....
21	Whole area.	S. E.	N. E.	12	21	28	11	23

* The negative sign indicates that the precipitation ceased *before* the passage of the cyclone.

† Progression was north-easterly from Long Island to north-eastern Massachusetts, with later rains in Vermont.

‡ Data indicate a north-easterly progression but are too meagre to determine the rate.

The conclusions derived from the above investigation may be summarized as follows:

1. The characteristics of the storms under discussion, as far as relates to their precipitation, are largely peculiar to each storm. This is seen in the amounts of the precipitation (Table I.) its distribution (description of each storm and Table II.) in the relation of the position of the storm centre to the times of beginning and ending of rain or snow (Table II.) and in the rate and direction of these times (Table III.) Limiting values and averages can be derived from these tables of the several characteristics, but they would have only an approximate value, on account of the small number of storms examined. The prominent individual features have already been mentioned; others can be derived from an inspection of the tables. There are, however, certain indications of common features in these storms which it may be well to note, with the caution that they depend upon very few storms.

2. In each of the northern group of cyclones, seven in number (No. 10 not discussed as explained above) the maximum area, with two exceptions, (one of which is doubtful) is south of the path of the cyclone, and sufficiently removed from it to indicate a decreased precipitation at the storm path (Table II).

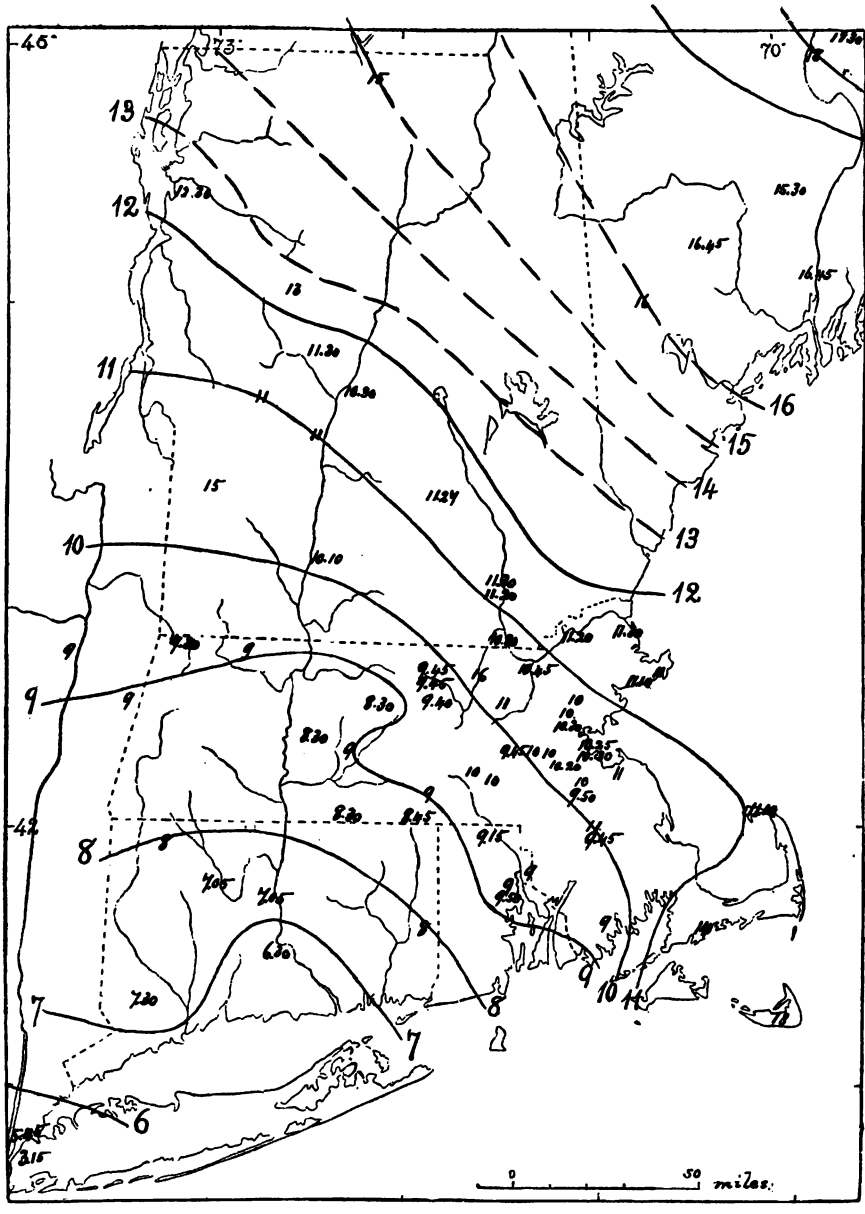

CHART III.—*Times of beginning of rain, October 13, 1885.*

The times are reckoned from 0 to 24 hours, midnight to midnight; that is, afternoon hours are the usual times increased by twelve. Lines of equal time are drawn for every hour. The broken lines are uncertain because of the lack of observations.

3. In each of the southern group, four in number, the maximum area is north of the storm path (Table II).

4. In each of the group, Nos. 17-22, in which the cyclone moved far north of the district, the maximum area is far from

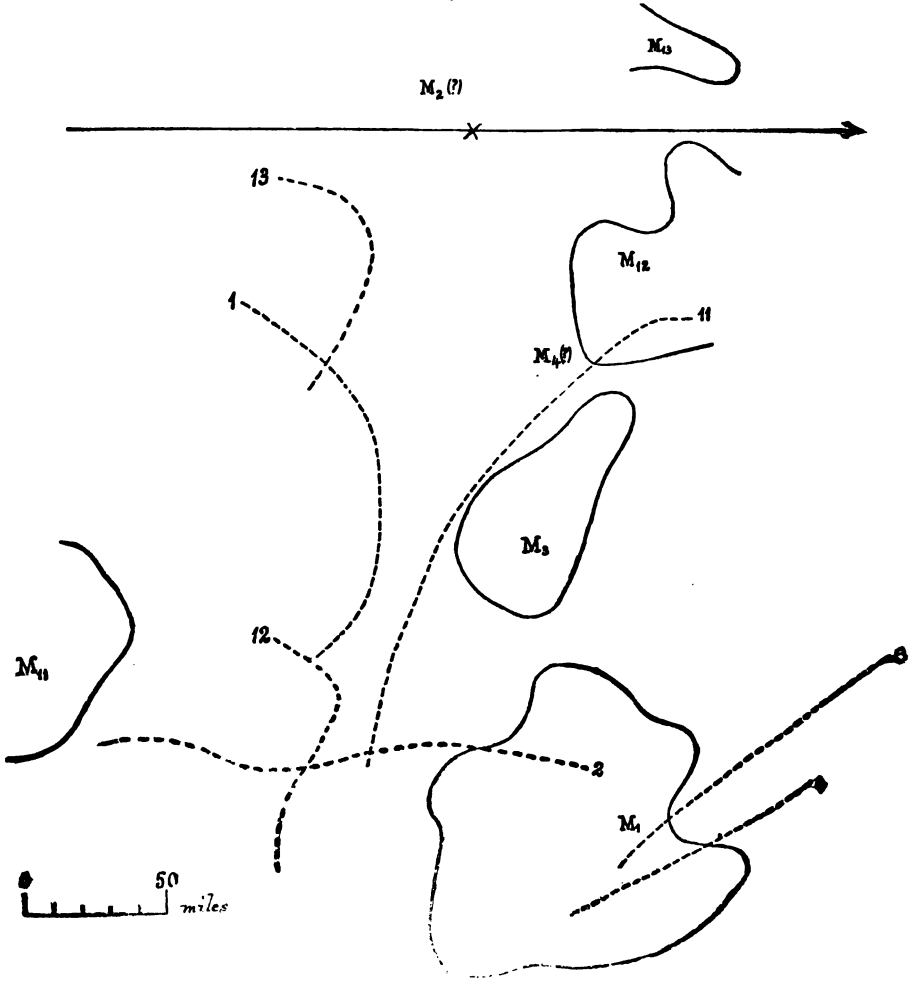

CHART IV.—*Combination chart for northern group, showing relation of maximum and minimum areas of precipitation to path of the cyclone.*

M denotes position of maximum area, the subscript, the current number of the cyclone; the full lines, the region where the precipitation was 0.8 of the maximum; the dotted lines the region of minimum precipitation, usually 0.1 or 0.2 of the maximum. The figures adjacent to the lines are the current numbers of the cyclones

the centre towards the southeast (Table II.). This of course does not indicate that the real maximum of the storm itself was southeast of the centre, for the observations are all far south of the storm path, but it does show that the precipitation does not

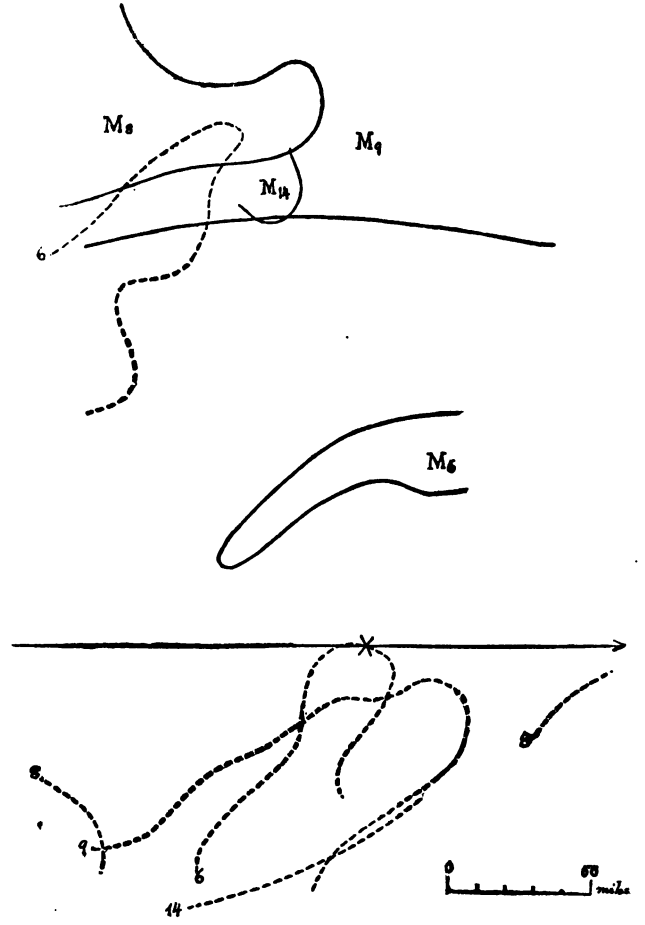

CHART V.—*Combination chart for southern group, showing relation of maximum and minimum areas of precipitation to path of cyclone.*
[Symbols as in chart IV.]

diminish uniformity from the path southwards, but that there are maxima south of the path.

In order to illustrate these facts further, two charts are here given showing the position of the precipitation line which is 0.8

of the maximum, the approximate position of the maximum point itself (indicated by the letter M), and the position of the line of minimum precipitation noted. This is a dotted line and is usually 0.1 or 0.2 of the maximum precipitation. Chart IV is for the northern, Chart V for the southern group. In constructing them, the arrow was drawn upon tracing paper, and then carefully placed over the track of each storm in turn, care being taken to have the point marked x centrally located in longitude. The subscripts and figures adjacent to the lines, denote the number of the cyclone in this paper. The values given in Table II, columns two and three, were derived from these charts. From these charts an additional fact is shown.

5. The minimum lines of the southern group lie very near the storm path on the southern side, averaging about fifty miles from it. In the northern group, they are further removed from the path. In both cases they lie near the southern coast, the limit of the district.

6. Superposing these charts upon a map of New England, with the storm tracks coincident with the average of the two groups, it has been found that the maxima of the two groups very nearly coincide, indicating that the greatest precipitation in both classes lies in the line of latitude extending across Vermont, New Hampshire and Maine, about 75 miles north of the Massachusetts boundary. The average maximum of the group, Nos. 17-22, lies in the latitude of central Massachusetts.

From tables III and IV, the following are derived:

7. The direction of movement of the front and rear of the precipitation generally coincides with that of the cyclone; there are however, marked instances of departure: one of these, No. 20, is probably only apparent as the cyclone was at the time of the beginning of the rain moving in an abnormal northwestern path, its general direction being northeasterly; the others, Nos. 17, 19, and 21, are summer thunder-showers, which it is well-known, often more at a large angle from the general direction of the cyclone within whose influence they form.

8. The rate of progression does not agree with that of the cyclone, as already pointed out. In the front of the cyclone, there

are five instances in which the precipitation moved faster than the cyclone, three in which it moved less. In the rear of the cyclone all of the instances, five in number, show a slower movement of the precipitation, in two of which, Nos. 9 and 11, it is quite marked.

These conclusions close the discussion of the first division of the subject. Attention will now be given to those cyclones which approach New England from the south.

II. CYCLONES APPROACHING NEW ENGLAND FROM THE SOUTH.

The study of cyclones of this class has been pursued upon the same plan as that of the former class. The results will therefore be given in the same form. Several subdivisions might be made, according to the previous history of the cyclone, whether it was generated within the limits of the United States, or entered it from tropical waters, or entered New England from the middle Atlantic ocean. These subdivisions were made in the investigation, but as the number of cyclones under discussion is small, they will all be considered in one division arranged chronologically, and the peculiarities due to their previous course mentioned as the investigation is described. The following table gives in condensed form the general characteristics of each cyclone. The headings have the same significance as in Table I.

TABLE V.

General characteristics of cyclone.

Reference No.	Date of passage.	Pressure at centre.* (inches)	Hourly Velocity (miles)	Precipitation.		
				Kind.	Max. am't. † (inches)	Duration. (hours)
23	Jan. 28, 1885.	29.5 d	54	Snow.	1.2	22
24	Mar. 15, 1885.	29.4 d	33	Rain and Snow.	1.2	.....
25	Mar. 19, 1885.	29.3	36	Snow.	.....	.....
26	Apr. 4, 1885.	29.4 d	28	Rain.	1.5	.....
27	Oct. 21, 1885.	29.8 d	33	Rain.	2.8	6
28	Nov. 2, 1885.	29.6 d	50	Rain.	3.7	8
29	Nov. 9, 1885.	29.5 d	45	Rain.	2.9	60
30	Dec. 31, 1885.	29.8 i	26	Rain.	1.9	15
31	Jan. 9, 1886.	28.7	31	Snow.	1.9	15
32	Feb. 15, 1886.	29.5 d	53	Rain.	0.5	1
33	Apr. 7, 1886.	29.8 i	.....	Rain and Snow.	3.4	42
34	May 9, 1886.	29.5 i	26	Rain.	2.6	22
35	May 25, 1886.	29.3 d	19	Rain.	1.1	6

* The letters *d* or *i* indicate that the pressure was either diminishing or increasing during the passage of the cyclone over or near New England.

† The values in this column are the average of the three highest records reported.

The paths of the central depression in each of the cyclones which traversed New England have already been given in dotted lines upon Chart I. Those given are Nos. 23, 24, 26, 27, 28, 29, 30, 31 and 32; of those omitted No. 25 moved northeasterly in the Atlantic far from the coast, No. 33 turned easterly into the ocean in New Jersey, No. 34 moved northeasterly in the Atlantic about thirty miles from Nantucket, and No. 35, which developed east of New England, moved northeasterly along the Maine coast. A more detailed description of each cyclone will now be given.

23. Jan. 28, 1885. This severe cyclone developed in the west, moved southeasterly into Missouri, thence into the Atlantic from New Jersey, and thence rapidly across the Atlantic in a northeasterly direction, occupying but three days for its ocean transit. It was increasing in violence as it passed New England. The precipitation was wholly snow, with its maximum amount in northern Vermont.

24. Mar. 15, 1885. This storm approached the coast from the ocean, and increased in violence as it passed over New England. Its precipitation was rain and snow, and distributed with a maximum in southeastern Massachusetts, not far from the central path.

25. Mar. 19, 1885. The precipitation in this storm was light snow at scattering stations. The storm itself was severe on the Atlantic, but moved too far from the coast (about 450 miles) to have much influence on the conditions over the land.

26. Apr. 4, 1885. This cyclone was formed in Colorado, moved southeasterly into Arkansas, thence northeasterly to Delaware and along the coast. The rainfall was abundant, and shows well defined maximum areas in Rhode Island and eastern Massachusetts, along the Connecticut river in Massachusetts and Connecticut, and again in northern Vermont. The rains were for two days, with times of beginning and ending not well determined.

27. Oct. 21, 1885. This was not a severe storm, but it increased in violence as it approached from North Carolina where it had formed. The rain was very heavy in northern Vermont, over

two inches having fallen in the northern half of that state, but the amount diminished southeasterly to 0.1 inch at Nantucket.

28. Nov. 2, 1885. This cyclone moved rapidly from the North Carolina coast, and was attended by severe gales on the coast. The rainfall was very heavy, exceeding two inches along the Connecticut River in Massachusetts and Connecticut. Four inches fell in central Long Island and southern Connecticut. This large amount fell in the short time of fourteen hours. The region of heaviest rainfall corresponds closely with the path of the centre of the storm, and this is the only instance among the forty storms investigated in this paper where this is unmistakably the case.

29. Nov. 9, 1885. This cyclone entered Rhode Island from the Atlantic, and was preceded by rain for two or three days, which ceased as the centre passed. After leaving Newfoundland it journeyed leisurely across the ocean reaching the coast of Spain in nine days. The rains in New England exceeded two inches in central Massachusetts, southern New Hampshire and northwestern Connecticut. The continuance of rain for several days in advance of the storm possibly indicates its formation at the time, in the Atlantic near New England.

30. Dec. 31, 1885. This cyclone formed in Virginia and was not a severe storm. The precipitation was not heavy, except in a narrow strip along the Connecticut River in Massachusetts and Connecticut, where it exceeded 1.5 inches.

31. Jan. 9, 1886. This was a very violent storm, and exhibits the characteristics of a cyclone to the greatest extent of any storm in this class. It was also more severe than any cyclone investigated in this paper, with the possible exception of No. 13 already described. It was better situated for observation than the latter, and will accordingly be specially examined later on. It originated south of Texas, and moved along the coast with a pressure at the centre of only 28.7 inches. It lost its energy and was dissipated north of New England. The precipitation was snow irregularly distributed. See Chart VI.

32. Feb. 15, 1886. This cyclone moved with great rapidity from southern Texas where it was first observed; it passed well

into the ocean before it was dissipated. The rains were of short duration, light, and not general over the district. The maximum amount, 0.5 inches, seems to be near the path of the storm in southern and central Vermont.

33. Apr. 7, 1886. This cyclone had a peculiar path. It moved from the northwest in a southeasterly direction to the Gulf of Mexico and then curving northeasterly, advanced rapidly towards New England with increasing energy. On reaching Delaware, however, it was checked in violence and ceased its movement; after lingering in New York state with its centre variously defined, it again developed sufficient energy to move on, and and entered the ocean from New Jersey, traveling easterly south of Long Island. The rain and snow falling in New England were heavy, continuing for nearly two days. Over two inches were recorded at Connecticut stations and in northern Massachusetts and southern Vermont, and 3-4 inches fell in western Long Island, the nearest point to the abnormal movements above noted.

34. May 9, 1886. This storm came from Texas, entered the ocean from Virginia, and moved northeasterly passing not far southeast of Nantucket. The rains attending its passage were heavy especially in Massachusetts, Rhode Island, and Connecticut. The maximum area, exceeding two inches lies in the Hudson valley.

35. May 25, 1886. This cyclone seems to have originated in the Atlantic east of Massachusetts and developed some violence as it passed along the Maine coast. The rainfall was in the form of light showers on several days. The maximum area was along the southeastern coast, and also in northern Vermont, where a single station reports over two inches.

The foregoing description shows that while the storms of this class all approached New England in paths not widely divergent, they were quite different in their origin. Three, Nos. 23, 26 and 33, are examples of cyclones which enter the country in the northwest, or else are there formed, move southeasterly, then curve to the northeast. Sometimes these cyclones actually pass into the Gulf of Mexico, as was the case with No. 33, when they return to the country with redoubled energy. None of the cyclones

enumerated are complete examples of those long-lived cyclones which form in tropical waters, move northwesterly to the Gulf of Mexico, curve slowly to the northeast, and then with increased speed move along the coast and across the ocean. Cyclone No. 20, entered the country from the West Indies but passed northwards to the lakes and thence northeastward, and has, therefore, been considered under the first-class. It will be noticed, also, that none of the cyclones of this class occurred in the summer months. This is the usual fact, though some are occasionally observed, especially in August.

The further study of these cyclones has been pursued on the same plan as that already described in the preceding division of this paper. Tables VI, VII and VIII give in condensed form the results of this study, which are given without further comment. Their explanation is the same as that of Tables II, III, and IV, respectively.

TABLE VI.

Relation of the precipitation to the path of the cyclone.

No.	Distance of max. area from path. (miles)	Direction of max. area from path.	Distance of center at begin of prec. (miles)	No. of records.	Direction of centre at begin. of prec.	Distance of centre at end of prec (miles)	No. of records.	Direction of centre at e nd of prec.
23	250	N. W.	400*	7	S W.	400*	7	N. E.
24	40	S. E.	.....	.....	.....	.....	.....	.....
26	120	N W.	366	26	S. W.	164	22	E.
27	100	N. W.	120*	11	S. W.	190*	6	N.
28	0	.....	320*	8	S. W.	100*	29	N W.
29	50	W.	.....	.....	.....	110*	9	S.
30	30	N. W.	354	51	S. W.	102	23	S. E.
31	10	N. W	456	34	S W.	117	43	N N. E.
32	30?	S. E.?	148	19	N.	173	17	N. E.
33	.....	.....	550*	23	S. W.	.....	.....	.....
34	120	N. W.	470*	6	S. W	130*	6	S. E.
Average.	61	N W.	354			165		

* Determined from stations in eastern Massachusetts only.

TABLE VII.

Relation of time of beginning of precipitation to the position of centre of the cyclone.

No.	Geographical area.	Direction of motion of prec. front.	Direction of motion of cyclone	Interval in hours.	Hourly rate of prec. front. (miles)	Hourly rate of cyclone (miles)	Interval before arr. of cyclone. a. (hours)	b. hours)
23	Eastern Mass.	.....	E.	.....	.....	35	17	.....
24	Vt., Mass., R. I.	E. or S. E.*	N. E.	.....	.....	.....	.....†	7
26	Eastern Mass.	.....	E.	.....	.....	9	19	.....
27	Mass., R I.	E.	N. E.	7	10	33	5	—1‡
28	Eastern Mass.	.....	N.	.....	.....	50	6	.....
29	Eastern Mass.	.....	N.	.....	.....	.....†	.....†	.....
30	Whole area, except Me.	E. N. E.	N. E.	8	16	29	10	8
31	Eastern Mass.	N. E.	N. E.	.....	.....	26	13	.....
34	Whole area.	N. N. E.	N. E.	18	18	18	26	21

* Data too meagre to determine more closely.
† Track in Atlantic and not charted.
‡ The negative sign indicates that the centre had passed before precipitation began.

TABLE VIII.

Relation of the time of ending of the precipitation to the position of the centre of the cyclone.

No.	Geographical area.	Direction of motion of prec. rear.	Direction of motion of cyclone.	Interval in hours.	Hourly rate of prec. rear. (miles)	Hourly rate of cyclone (miles)	Interval after pas. of cyclone. a (hours)	Interval after pas. of cyclone. b. (hours)
23	Eastern Mass.	.....	N. E.	.....	.....	50	5	....
27	Mass., R. I., Conn.	E.	N. E.	4	20	33	2	4
28	Whole area.	N. E.	N.	13	26	50	−2*	6
29	Whole area.	N. E.	N.	11	28	47	—+	1
30	Conn., R I., Mass., Me.	N. E.	N. E.	16	12	21	1	6
31	Eastern Mass.	.....	N. E.	.....	.....	38	2	.....
34	Whole area.	E.	N. E.	14	12	33	−8*	4

* The minus sign indicates that the precipitation ceased before the cyclone had passed. + Track in Atlantic and not charted.

A careful examination of the results collected in these tables seems to warrant the following conclusions, applicable to the cyclones of this class; the numbering is continued from the conclusions of the first division.

9. The precipitation is, with one exception large; if we include in this division cyclones Nos. 1, 11, 18 and 20 of the former division which were similar to those under discussion in their origin, but moved to the lakes before approaching New England, we shall find that the average maximum precipitation of the sixteen storms is 2.36 inches, while that of the seventeen remaining, which came from west or northwest is 1.74 inches.

10. The position of the maximum area of precipitation in relation to that of the path of the cyclone cannot be so well determined as in the former division on account of the narrowness of the territory on either side of the path. The average given in Table VI shows that the area is on the northwest of the average path, but this result may be fictitious, because the paths lie principally on the east of the territory covered by the observing stations, and the conditions further east are not known. In the former division, the investigation pointed to the conclusion that the maximum area of precipitation was not near the path of the cyclone, but well separated from it. In the cyclones of this class however, the testimony favors the conclusion that the maximum area lies on, or near the path.

11. The direction in which the front and rear of the precipitation advances deviates in certain instances (Tables VII and VIII) from that in which the cyclone is moving, but not to so

marked a degree as in the former division. In general the two directions agree.

12. But the rate of progression is quite different. In no instance does the precipitation, front or rear, move as fast as the cyclone itself, (Tables VII and VIII). Averaging the eight cases, we find that the hourly rate with which the precipitation, front or rear, advances is 18 miles, that of the centre 33 miles. As the progression is northerly or northeasterly, this result means that as a storm centre approaches, it begins to rain or snow in the southern part of the district at a correspondingly earlier time than in the northern or northeastern parts.

THE CYCLONE OF JANUARY 9TH, 1886.*

The cyclone which traversed New England January 9th, 1886, was a remarkably complete example of those cyclones which move along the eastern states from the Gulf of Mexico. It was not only unusually well-developed and severe, but it crossed that part of New England where the observing stations are most numerous, and where observations of the meteorological conditions are made with especial fulness. The centre passed near the U. S. Signal stations at New York, New London, Boston and Portland, and almost directly over the stations at Providence, Blue Hill and Chestnut Hill and near that at Central Park, N. Y., where self-registering instruments are in constant use. The opportunity was therefore especially favorable for studying the cyclone in minute detail, particularly those characteristics in the line of advance of its centre. The request for detailed observations made during Jan. 8th, 9th, and 10th met with a most generous response, and is here gratefully acknowledged.

This cyclone developed north of Texas on the 6th and moved southeasterly to the Gulf of Mexico; curving to the northeast it re-entered the country on the 7th. On the 8th it moved easterly to Alabama with a pressure at the centre of 29.5 inches; it then

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*This section is a revision ot a paper read at the meeting of the New England Meteorological Society, April 20, 1886.

curved to the northeast, the pressure falling at its centre to 28.7 inches, and on the 9th moved rapidly over Delaware, Rhode Island, eastern Massachusetts, and western Maine to the St. Lawrence. It diminished in violence and probably was dissipated north of Canada. There were peculiar conditions prevailing at this time over the country east of the Rocky mountains, especially of temperature, to which the unusual development of this cyclone must be referred. On the morning of the 9th, the pressure ranged from 30.8 inches in the northwest to 28.7 inches at the centre of the cyclone in Delaware. The temperature ranged from —50° (50° below zero Fahr.) to 30° at the centre of the cyclone and 60° in southern Florida. An area of excessively cold air was therefore entering the country and pressing southeasterly. This area in its advance over the country was one of the most intense on record, penetrating far into the southern states after the passage of the cyclone. The *Monthly Weather Review* for January, 1886, devotes much space to this cold wave, with chart illustrating its progress on successive days. The U. S. Signal Service printed its tri-daily maps,* in addition to its usually daily map, for five successive days, for the convenience of students. Much assistance has been obtained from these maps in this investigation.

The study of the observations made in New England during the passage of this storm has not been confined to precipitation, but includes all the conditions for which records are available. These will be discussed in order, and some conclusions derived from the results obtained. The following table is given as a sample of the many records available for discussion. It gives only a part of the observations at the stations selected, which are chosen because lying very nearly in the central path of the storm. The minimum pressures given are those obtained at the regular hours of observation and are not necessarily the lowest reached, except at Providence and Blue Hill observatories, where there are self-recording barometers. The maximum tempera-

* It may be well to point out an important misprint in these maps. The third map for each day contains the observations at 10 P. M., not 11 P. M., as stated.

TABLE IX.

Observations at stations near central path of storm, Jan. 8th and 9th, 1886.

	New Haven.	New London.	Providence.	Blue Hill.	Boston.	Newburyport.	Portland.
Pressure, 9th, 7 a. m	28.861	28.872	28.97	28.973	28.969	29.137	29.251
" " 3 p. m	29.043	28.921	28.80	28.713	28.728	28.772	28.808
" " minimum	28.861	28.801	28.69*	28.687†	28.728	28.772	27.808
Temperature, " 7 a. m	11	21	27	26	26	7	2
" " 3 p. m	13	19	23	24	28	18	16
" " maximum	28	28	28	30	29	21	20
Wind direction, " 7 a. m	N. E.	N. E.	N.	N. E.	N. E.	N. E.	N
" " " 3 p. m	W.	S. W.	S. W.	S. W.	S. W.	.....	N
" velocity, " 7 a. m	39	29	26	57	38	high	31
" " " 3 p. m	11	19	.....	36	12	light	14
" " " maximum	44	32	29	65	64	53	40
Time of maximum	.....	9th, 5:45 a. m.‡	9th, 3 a. m.	9th, 5 a. m.	9th, 4:45 a. m.	9th, 4:40 a. m.	9th, 5:25 a. m.
Snowfall, melted	0.64	1.47	1.90	0.45	1.10	1.82	0.24
Snow began	8th, 11:30 p. m.	9th, 12:10 a. m.	8th, 11:30 p. m.	night	9th, 12:30 a. m.	9th, 12-1 a. m.	9th, 3 a. m.
Snow ended	9th, 2 p. m.	9th, 8:05 p. m.	9th, 3 p. m.	9th, 2 p. m.	9th, 4 p. m.	9th, 6 p. m.	9th, 7:25 p. m.
Cirri first noted	8th, 11 a. m.	.....	.....	8th, 3 p. m.	8th, 3 p. m.	8th, 2 p. m.	8th, 11 p. m

* At 1:45 p. m.

† At 2:40 p. m.

‡ Also a second maximum of 40 miles between 1 and 1:30 p. m.

tures and wind velocities are in all cases from self-recording instruments. The extreme violence of the wind is of especial note.

The characteristics of this storm will now be pointed out, as indicated by the several meteorological elements.

(1) *Pressure.*—The lowest pressures recorded were 28.69 inches, as given in the above table. This extreme value was noted at Philadelphia, Providence and Blue Hill, and has rarely been recorded in New England. After the storm entered the state of Maine, the pressure rose slowly at the centre. The accompanying map, chart vi, contains the path of the centre of the cyclone across New England, carefully

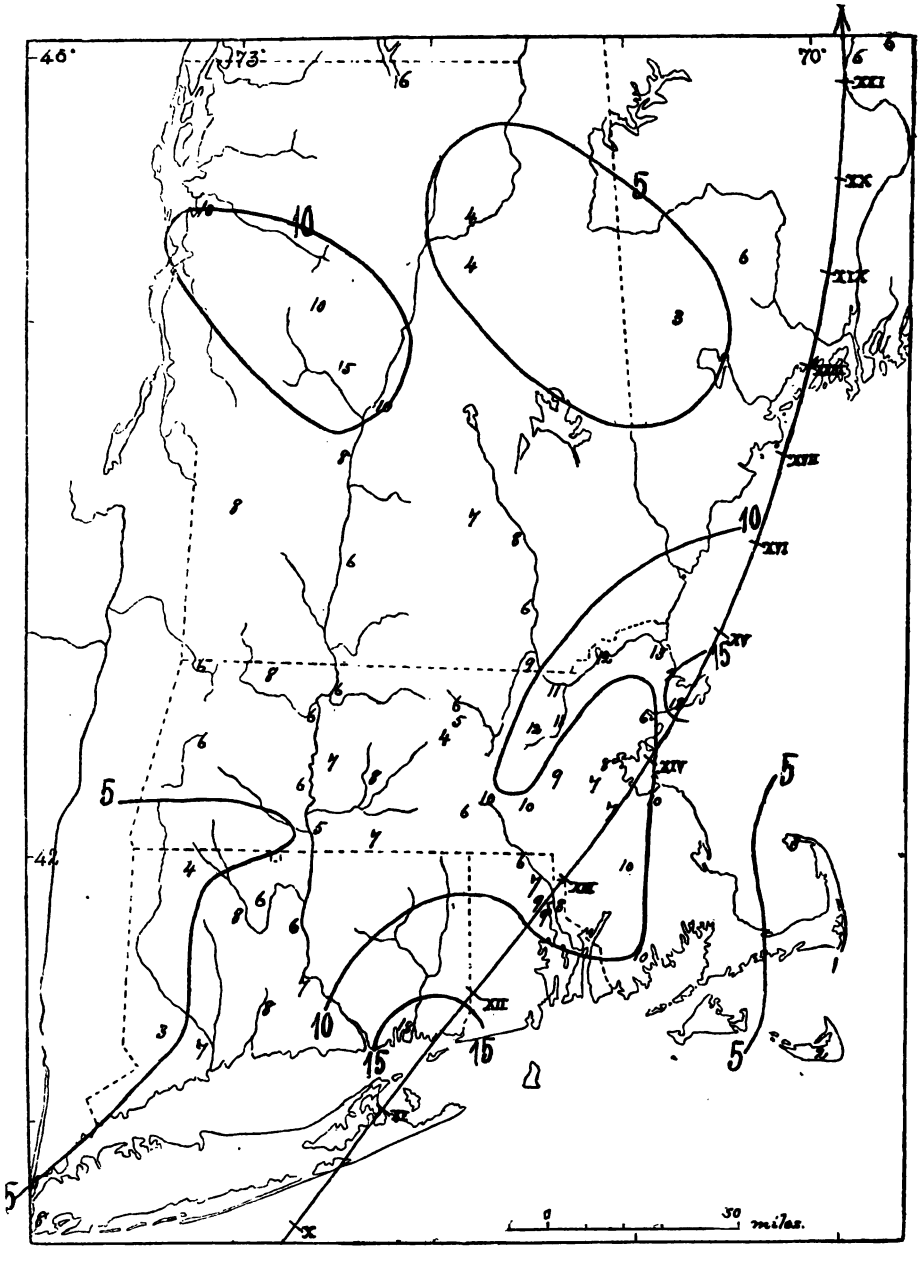

CHART VI. *Part of cyclone, January 9, 1886, with estimated snowfall.*

The Roman numerals indicate the hours at which the cyclone centre occupied its successive position. The snowfall is estimated in inches, and the lines of equal snowfall drawn at intervals of 5 inches.

drawn from the observations of pressure. The hours, indicated by Roman numerals, are in the standard time of the 75th meridian and are numbered continuously up to 24, the afternoon hours being designated by those between 12 and 24.

Besides the extreme lowness of the pressure, the fluctuations of the values from hour to hour are of especial value. In order to illustrate the barometric movements, the following chart is given, chart vii, which contains the records of the self-registering barometers at Blue Hill, Providence and Central Park, New York. At all of these stations Draper's self-recording pencil barometer is in use. The published curves are tracings from the original records furnished by the observers themselves. The Blue Hill tracing is given without alteration, but the horizontal scale of the Providence record has been doubled, to accord with that of the former station, the vertical scales being identical. For a similar reason the vertical scale of the Central Park record has been increased by one-half, the horizontal scale agreeing with that at Blue Hill. With these changes, made necessary for publication in a common scale, the curves are given as made by the respective instruments. The minute fluctuations are represented only approximately. The curves are for an interval of twenty-four hours at each station, and the hours are as follows, so selected that the lowest points of the curves may lie approximately in the same vertical line.

New York, 7 P. M., 8th; 7 P. M., 9th.
Providence, 11 P. M., 8th; 11 P. M., 9th.
Blue Hill, 12 P. M., 8th; 12 P. M., 9th.

The corrections to these curves to reduce to sea-level are respectively: New York, +0.11; Providence, +0.07; Blue Hill, +0.68 inch.

The barometric curves show that the fall of pressure was not uniform but much more rapid about eleven hours before the lowest point was reached than at other times; they also show to a marked degree the peculiar fluctuations, which are usually recorded whenever a well-developed cyclone is passing, the cause of which is not yet clearly understood. These fluctuations are most marked in the Blue Hill record. The rise of the pressure

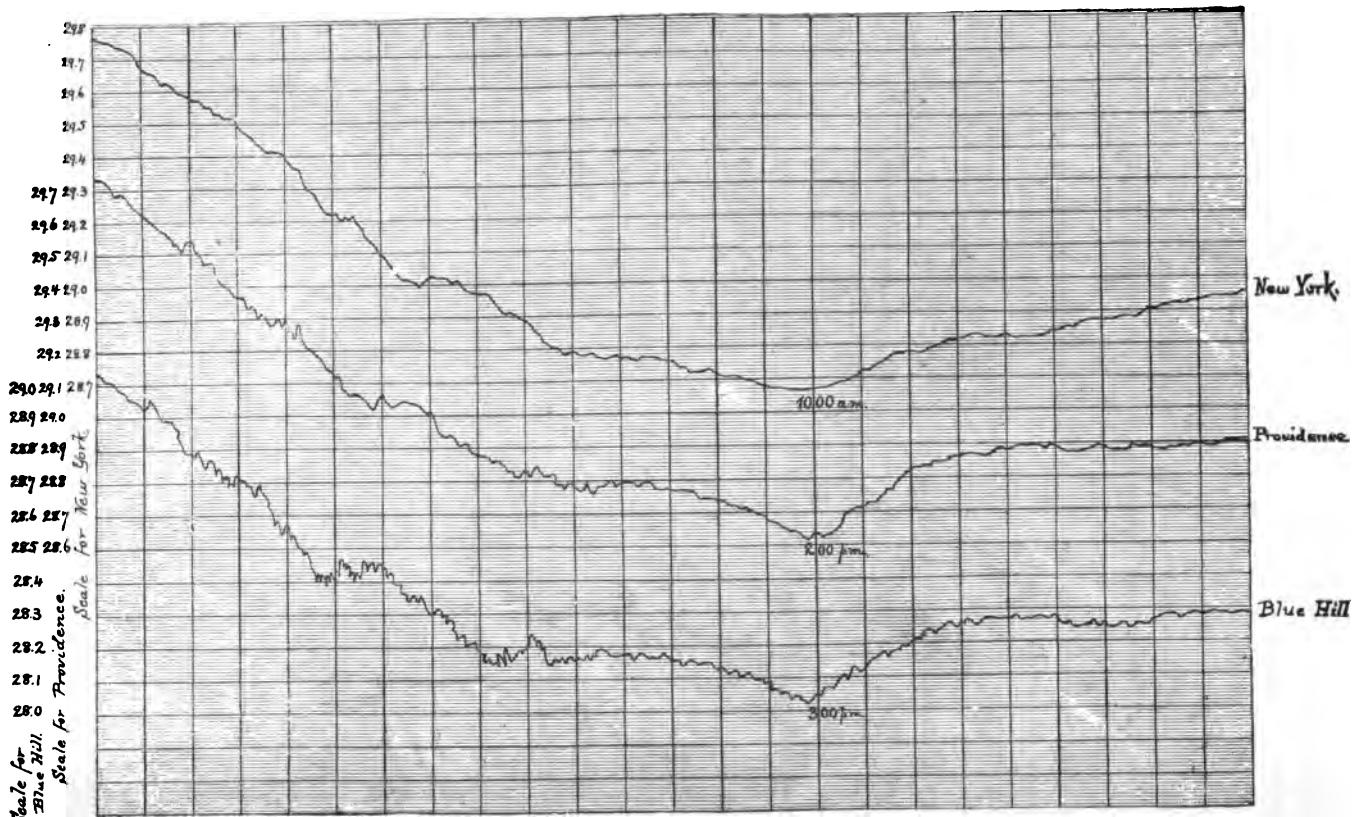

CHART VII. *Barometric Curves at New York, Providence, and Blue Hill.*

Vertical scale is barometric pressure in inches; horizontal scale is time in intervals of one hour.

after the centre had passed was slower and more uniform than the fall preceding its passage.

(2) *Temperature.*—The temperatures as noted at the many stations in New England were near or below freezing at the beginning of the storm, followed by a rapid fall after its passage, as the intense cold wave from the west immediately followed. There are two Richard thermographs, one at Chestnut Hill, Mass., the other at Providence, whose records have been available for discussion, and also a Draper thermograph at Central Park, New York. As these curves show very peculiar fluctuations, they are here reproduced, chart viii. The curves at Chestnut Hill and Providence are given in the exact scale of the original record. The scale of the Draper thermograph is very much greater than that of the others; it has therefore been reduced in copying to the former scale. The scale as printed is exactly that of the original record at the two former stations.

An examination of these curves shows that the records at Chestnut Hill and Providence substantially agree. They indicate that the usual diurnal fall of temperature in the night was checked at about midnight, Jan. 8th, and in its place a rise of temperature of about 7° took place, which reached its maximum just before sunrise on the 9th. This was followed by a fall of 15° and a similar rise a few hours later, the second maximum agreeing approximately with the first. After this maximum, which occurred near the usual time of the daily maximum (2 or 3 P. M.), the temperature rapidly fell. The New York curve shows an agreement with the other records in some respects, but is dissimilar in others, as may be seen by comparing them carefully. The question arises, to what extent these fluctuations are due to the cyclone and to what to the usual diurnal fluctuation, as modified by the cloud conditions of the sky. It is clearly impossible to decide this question with certainty, but its answer may be attempted by noting the points of agreement and disagreement in the curves and the attendant conditions. The storm-centre passed New York, Providence and Chestnut Hill at about 9:30 A. M., 1 and 2 P. M. respectively. It passed about fifty miles southeast of New York and nearly over the other sta-

tions. At all of the stations it was snowing from about midnight of the 8th until 3 or 4 P. M. of the 9th, so that the cloud conditions were similar. We notice that the three curves agree in the checking of the diurnal fall of temperature on the evening of the 8th, and in a rapid rise, which occurred at New York about 4 P. M., and at the other stations near midnight. Each shows the same general condition for six hours following—temperature nearly stationary with a slight fall and subsequent rise. Each shows the fall of 10° to 15° immediately succeeding, but

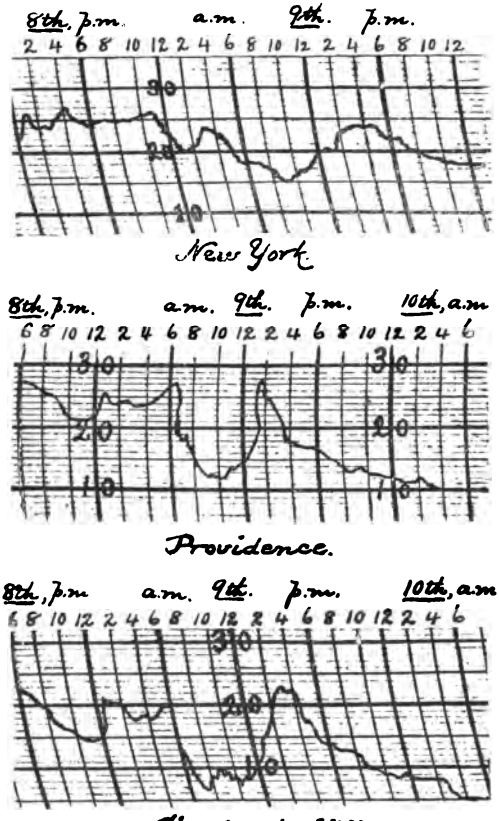

CHART VIII. *Thermometric curves at New York, Providence and Chestnut Hill.*

Vertical scale is temperature in degrees Fahrenheit; horizontal scale is time in intervals of two hours.

at New York the fall was more gradual and the later rise also more gradual, so that the second maximum of the 9th occurred at New York even later than at the other stations. The curves therefore disagree in the length of time between the two maxima, which is thirteen hours at New York, seven hours at Providence and nine hours at Chestnut Hill. The minimum point at New York occurred at about the time that the storm-centre was nearest, while at the other stations the second maximum had been reached at its passage. In interpreting this comparison, it may be considered that the first named points of agreement are due to the advancing cyclone. The records at New York precede those at the other stations by eight hours; the storm-centre at midnight was moving with an hour velocity of about twenty miles, much slower than when it traversed New England on the following morning. The difference in time corresponds quite well with the rate of the cyclone. We may then infer that the checking of the diurnal fall of temperature, the subsequent rise of about 5°, the approximately stationary condition for six hours, and the sudden fall of temperature were due to the cyclone, and occurred when the centre was distant about 600, 500, 500–250, and 250 miles respectively. The rise of temperature on the morning of the 9th may also be due to the cyclone, but the records do not permit us to locate it at any definite relation to the centre of the cyclone. The rapid fall on the evening of the 9th indicates the advance of the cold wave which immediately succeeded the passage of the cyclone.

(3) *Wind.*—The wind velocities were high as the storm approached, were light when the centre was nearest, and increased again after its passage. The second maximum was not equal to the first at the majority of stations. The following table contains the maximum velocities (in miles per hour) as the storm approached, at those stations furnishing the data. There is also given the corresponding direction of the wind, the time at which the maximum velocity occurred, and the distance and direction of the storm-centre at that moment. The distance in "hours" denotes the interval of time which elapsed before the centre reached its nearest point to the respective stations. The times are in each case on the 9th inst.

TABLE X.

Maximum wind velocities before the passage of the storm center, January 9, 1886.

Stations.	Max. Vel.	Direction.	Time.	Distance of Centre.	
				Miles.	Hours.
New York	44	N E.	4:40 a. m.	140	5
New Haven	44	N. E.			
New London	32	N E.	5:45 a m.	240	6
Providence	29	N. E.	3:00 a. m.	360	10
Provincetown	68*	N. E.	1:00 a. m.	470	13
Blue Hill	65	N. E.	5:00 a. m.	340	9
Boston	64	N E.	4:45 a. m.	360	9
Brattleboro'	28	N. W.			
Newburyport	53	N. E.	4:40 a. m.	380	10
Nashua	29	N. E.			
Portland	40	N. E.	5:25 a. m.	380	12
St. John	21	N. E.	10:00 a. m.	480	13
Average				350	10

* Estimated.

The records of the direction of the wind at Blue Hill and Boston show great fluctuations which were not so marked at New York, Providence and Newburyport. At the latter stations the wind changed with some fluctuations from northeast through the north to northwest. At Boston, the wind "boxed the compass" several times near noon of the 9th. At Blue Hill, the continuous record gives some very interesting results, which are of especial value from the situation of this observatory on the summit of an isolated hill, 650 feet above the sea-level. At 8:50 A. M., the wind, which had been blowing from the northeast, backed to the west and blew from the northwest and north until 12:15 P. M., with velocity diminishing from 30 to 8 miles per hour. At this time it became variable, blowing from all points of the compass, and settling to a southeast wind which gradually veered to the southwest by 3 P. M., the velocity increasing to its second maximum, 48 miles, at 4 P. M. These changes are interesting when compared with the corresponding barometric record. The point of lowest pressure was reached at about 2:40 P. M. Consequently, six hours before this, the wind changed abruptly and for three hours and a half blew from the northwest and north; then occurred the chief fluctuation when the centre of low pressure was still distant about 75 miles, and for two hours the wind blew not towards but *away* from the point of lowest pressure. As the centre passed directly overhead at Blue Hill, these records show the peculiarities of the wind movements in the path of the storm.

The continuous record at Central Park, New York, is at a station fifty miles from the centre and shows an absence of these peculiarities. At this station, the wind blew steadily from the northeast, (with two fluctuations at 12:10 A. M. and 5:30 A. M.) until 10 A. M., after the centre of lowest pressure had passed its nearest point, when it backed gradually through the north to the northwest and reached the west at 3 P. M.

(4) *Precipitation.*—The precipitation was in the form of snow, and as the wind blew violently, its amount at the several stations cannot be given with accuracy. It has seemed best to use the observers' estimates of the depth of snowfall instead of the records of melted snow, in examining the distribution of the snowfall, and the map, chart vi, is accordingly so drawn. As far as can be determined from such imperfect data, the maximum area lies in the path of the storm, as in the case of other cyclones which approach New England from the south.

As the snow was packed solidly by the wind, the amount of water obtained by melting a section of average depth was much larger than is usual. At Chestnut Hill and Providence one inch of snow yielded 0.21 inch of water, and the average of seventeen stations, where the determinations were carefully made, is 0.15 inch.

The snow began to fall at the several stations in the night or early morning, when the storm-centre was at an average distance of about 470 miles; it ceased falling when the centre had passed beyond the several stations to a distance averaging fifty miles. The duration of the snowfall was about fourteen hours, of which twelve and one-half were before and one and one-half after the passage of the storm-centre.

(5) *Cloud movements.*—The first cirri which heralded the advancing storm were noted at the several stations in the afternoon of the 8th. In Table IX are given the times at the stations mentioned. The average of the times at all the stations for which the data are available, which are situated nearly in the line of advance of the storm center, shows that the cirri began to gather about twenty-four hours before the arrival of the center, when its distance was about 950 miles, or about twelve hours before the snow began to fall.

Several observers made especial note of the partial breaking away of the clouds near the time of the passage of the center, followed by their gathering again. The observer at Newburyport remarks: "The sky was entirely overcast on the morning of the 9th until about 11 o'clock when the clouds broke sufficiently to enable me to see plainly that they [upper clouds] were moving from S. S. E., although the wind was N. N. E. Several times from 11 A. M. to 3 P. M., I observed the clouds again moving from S. E. or S. From 3 to 4 P. M., the clouds seemed to hang very low and were exceedingly black and heavy in N. E. and S. E., while they frequently broke away near the zenith and to the W. and S. W. of it, disclosing blue sky. (Snow was falling all the while in small quantity.) At this time (3 to 4 P. M.,) the motion of the clouds was from S. S. W., moving rather fast. As far as I could see, there appeared to be no upper clouds at that time." It should be noted that the storm center, (which has been taken in this paper as coincident with lowest barometric pressure) passed near Newburyport at about 2:50 P. M. The partial clearing above described, therefore preceded the passage of the centre.

The observations at the basis of the above description, have been further studied to see if they would throw any light upon the difficult subject of the mechanism of a cyclone. The special stations in New England are so situated as to give the conditions in the line of the storms advance, while the stations of the U. S. Signal Service outside of New England give the conditions at definite points on the western side. The conditions on the east cannot be given because the track passed so close to the coast line. An attempt was made to combine all the observations at the different stations upon a single chart in order to obtain a "composite" of this cyclone. The method consists of moving a piece of tracing paper from place to place, so that its centre shall fall successively upon the cyclone centre at the different times of observation. At each position, the observations at the several stations are located on the chart. In this way the successive records at any given station appear on the chart in their proper relation to the centre of the cyclone at the various times, and a combination chart is obtained which includes all the ob-

servations. The assumption of the method is that the cyclone retains a definite character from hour to hour to such an extent that the observations can be safely combined, though made several hours apart. Unfortunately there is abundant evidence that the assumption is false in the case of this cyclone, and the method was reluctantly abandoned. The barometric records have been carefully tabulated for the observations 8th, 10 P. M.; 9th, 7 A. M., 3 P. M., and 10 P. M.; (the three hours of the U. S. Signal Service telegraphic observations,) supplemented by observations in New England, and the evidence is conclusive that during the transit of the storm over New England it was undergoing rapid changes, at least in the conditions indicated by the barometric readings. The pressure was rising slowly at the centre but was relatively lower at stations removed from the centre, as the storm moved along. There was greater change on the left of the path of advance than on either preceding or following sides.

The storm was at its greatest intensity as it entered New England; the following chart, Chart IX, is therefore given to illustrate the observed conditions at this time. It is derived from all the observations available relating to pressure, temperature, wind direction and velocity. The individual observations of pressure and temperature are omitted in printing, but the full lines are the isobars or lines of equal pressure drawn at intervals of 0.1 inch, the dotted lines the isotherms or lines of equal temperature drawn at 10° intervals. The stations of observation are especially abundant on the upper part of the chart, preceding the centre. The observations of the wind are given at each station reporting them, as they are relatively fewer. The arrows indicate the direction, flying with the wind, and the adjacent numbers give the velocity in miles per hour. The centre of the cyclone at the time of observation was near Philadelphia. The corresponding charts for other others might be given, but the number of observations on which they depend is not so great as at 7 A. M. They show the changes in the conditions commented on above, which indicate that the storm had begun to decrease in violence.

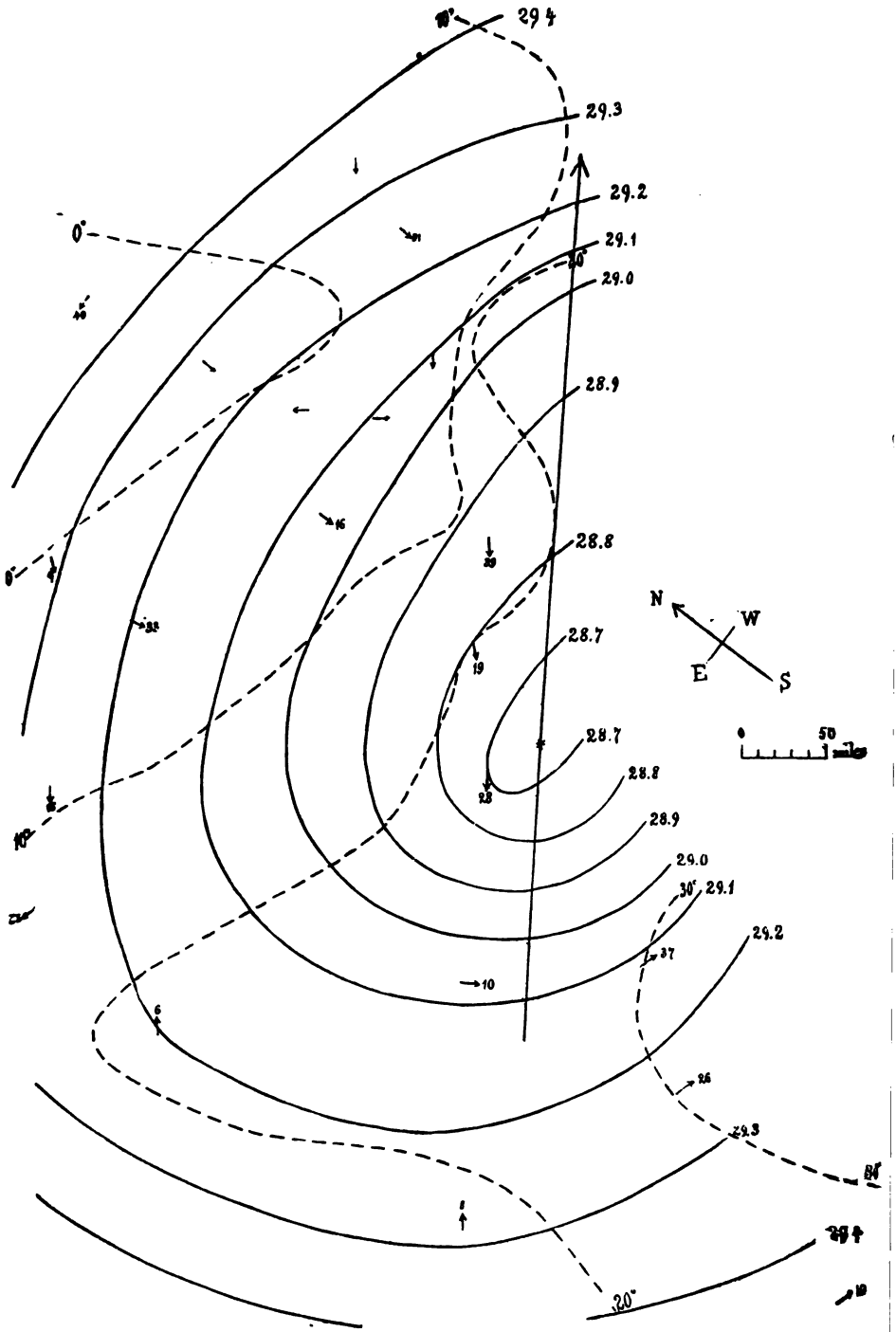

CHART IX. *Map of Storm, January 9, 1886, at 7 a. m.*

Full lines are isobars, dotted lines isotherms, arrows fly with the wind, figures adjacent to arrows denote wind velocities. The long arrow shows the direction in which the cyclone was moving.

The chart illustrates the severity of the storm at the time of observation. The closeness of the isobars is especially to be noted, the gradient in the steepest part being 0.1 inch for 22 miles. The crowding of the isolars 29.1 and 29.0 on the forward side of the centre is probably real, as it depends upon a number of reliable observations. The isotherms show the rise of temperature at the centre of the cyclone; they also indicate the approach of the intense cold wave from the north. The wind arrows show, with one or two exceptions, the direction required by theory about a central depression. The velocities are hardly comparable as they are made at the several stations under varying conditions of exposure.

The theory of the mechanism of a cyclone, which is at present received with the most favor, is in brief that at the centre of lowest pressure there is an ascending current of relatively warm, moist air. This current is fed by the surface winds, which blow from all directions towards the centre in a spiral direction, deviating from a direct line in a direction contrary to that of the motion of clock hands. The upper winds blow outward from this ascending column, curving in a direction the same as that of clock hands, and form at a great distance from the centre an annulus of relatively high pressure. Such a simple structure probably does not exist in a well-developed cyclone, though the theory may be true as a general outline. It has been known for some time that the real structure of a cyclone is far more complicated, and a clearer knowledge of it must be derived from the special study of such cyclones as the one under discussion. The detailed statement of the observations given above has already indicated several important facts which ought to be regarded in studies of this sort. In recapitulation, there may be mentioned as of chief importance the barometric fluctuations. The curves given in Chart VII show not only minor fluctuations, but also several distinct waves of rising and falling pressure, occurring in the course of the general fall of pressure. The three curves agree in four of these, which occur on the Blue Hill curve at 3–4, 5–7, 8–9:30 and 10–12 A. M., the second of them being the best marked.

These deflections may indicate minor ascending or descending currents, as some have thought, or they may be due to other causes; but they must be taken into account in any complete statement of the cyclonic structure. The absence of similar fluctuations on the following side of the cyclone is a second characteristic worthy of mention. That the preceding part of the cyclone is especially complicated is also indicated by the peculiarities in the temperature curves and in the wind records both of direction and velocity. The former have been carefully examined above, and it has been shown probable that they indicate real fluctuations in the cyclone itself. The latter have also been described in detail; the chief peculiarities noted were that the highest velocities occurred when the storm centre was distant about 350 miles, or ten hours before its arrival, and that the change of wind direction occurred several hours before the arrival of the centre. The clearing away of the clouds, also, which is sometimes regarded as coincident with the passage of the centre of lowest pressure, occurred several hours before the arrival of the latter. This storm therefore furnishes evidence of the complicated structure of cyclones. It would be possible to conjecture how these peculiarities may be accounted for, or at least to suggest such modifications in the structure as would include them, but it is not a part of the designs of this paper to enter the field of speculation.

There is one important need in meteorological observations which the discussion of this storm emphasizes, viz., that of an increased number of stations where continuous records of the several elements are made by self-registering instruments. Nearly all the peculiarities specified above were brought into view by the continuous records made at a very few stations, and would not have been discovered from observations at stated times even were the number of stations very numerous. Their further elucidation might have been possible had there been more stations furnishing similar records. It would be a great advantage for future researches if a number of stations with self-registering apparatus could be well distributed over the area visited by cyclones.

III.—CYCLONES WITH A SECONDARY DEVELOPMENT, OR INSTANCES IN WHICH TWO CYCLONES UNITE NEAR NEW ENGLAND.

In this group are included six cyclones of a more complicated character than those previously discussed. The formation of a second depression during the passage of a cyclone is not an unusual occurrence. It may happen in the case of any well-developed cyclone; indeed it is proper to regard a cyclone as a continual succession of depressions which are formed and dissipated in turn, rather than a definite organism moving along in a restricted path. It is probable that in a large area around the central depression minor depressions are frequently formed, which are after a time absorbed in the main depression. Or, one of the secondary depressions may attain a development exceeding that of the primary cyclone, and absorb the latter, continuing in a path which deviates to a greater or less degree from that previously pursued. These changes cannot often be observed, because observing stations in the path of the cyclone are not sufficiently numerous, and because stations where continuous records are kept are still more infrequent. But occasionally the phenomenon occurs on so large a scale that it is well defined. The auxiliary depression may be formed several hundred miles from its primary, and pursue for a time a wholly independent path. Either may absorb the other, gaining in energy and with greater or less deflection in its path.

Another interesting phenomenon is the union of two cyclones which had a wholly independent origin. It is not always possible to tell whether two cyclones which unite are wholly independent in their origin, or are examples of a primary cyclone with a secondary development. For this reason these two cases are considered together in this discussion. There are but six instances in all, and they have been considered solely with regard to the peculiarities in the precipitation reports. They will be first described in detail, continuing the numbering from the preceding sections. The following table contains the current number, with the date of passage of each storm. The date given is that for the cyclone, whether primary or secondary, which came from the south.

TABLE XI.

Date of Passage of Combined Cyclones.

Current Number.	Date.
36	February... 10, 1885.
37	April..... 27, 1885.
38	July..... 14, 1885.
39	September.. 23, 1885.
40	February.... 12, 1886.
41	March..... 22, 1886.

It was found inexpedient to attempt to tabulate the general characteristics of these storms in the manner of Table I and V, because each is a double storm. Two cyclones are in each case to be described, whose union occurs near New England, generally after the passage of one or both over or near the district. The data concerning the times of beginning and ending of the precipitation are quite meagre and also conflicting, on account of the dual nature of the storms. The detailed description of each storm therefore embodies the results which in the former division have been given in tabulated form.

(36) Feb. 10, 1885.—This cyclone moved from southern Texas to the Lakes as a severe storm increasing in violence. The pressure had fallen to 29.1 inches when the centre reached the Lakes. At this time a second depression appeared on the Connecticut coast, which probably formed near Long Island at a distance of about 450 miles from the path of the former. It moved northeasterly over New England with an hourly velocity of about 35 miles, and with its pressure at the centre diminishing from 29.1 to 28.9 inches. It is not known that the first depression continued its original path, though it may have done so, as there are no reports accessible so far north; it is probable that it was absorbed by the latter, which continued its journey into the Gulf of St. Lawrence. The precipitation was rain with some snow, and was heaviest in southwestern Connecticut. An amount exceeding two inches fell in an elongated region covering parts of Connecticut and Massachusetts and nearly coincident with the path of the second cyclone. The times of beginning and ending of the precipitation were not well marked; its duration in eastern Massachusetts was about seventeen hours.

(37) April 27, 1885.—This cyclone developed in Arkansas and moved to the Lakes, where it was reinforced by a depression from the northwest, the pressure at the centre falling to 29.6 inches. At this time a second depression appeared on the Virginia coast, which probably developed in that vicinity at a distance of about 500 miles from the path of the former. It moved into the Atlantic and passed by New England in a northeasterly direction about 150 miles from the coast with an hourly velocity of 47 miles. The primary depression advanced down the St. Lawrence valley as far as Montreal, and then ceased to maintain an independent existence. As neither path was very near New England the precipitation was not excessive; the maximum area, slightly exceeding one inch, was in southern Rhode Island, or in that part of the district which lies nearest to the path of the second cyclone. The duration of the rain in eastern Massachusetts was about 13 hours. The time of beginning of the rain was well marked, showing a northeasterly progression with an hourly movement of about 20 miles.

(38) July 14, 1885.—The primary cyclone came from the west reaching the Lakes with a central pressure of 29.6 inches. A subsidiary depression formed, which became well marked over Chesapeake Bay with a central pressure of 29.7 inches, about 400 miles from the former. The latter probably moved rapidly across New England in a northerly direction uniting with the former, though its exact path cannot be traced. The rainfall was not heavy, but amounts exceeding one inch were reported in western Connecticut and Vermont and the Hudson valley corresponding with the supposed path of the auxiliary depression. The rainfall front and rear moved in a northeasterly direction, but the data are not sufficient to determine the rate of movement. An interesting feature of this storm is the absence of thunder and lightning in connection with its passage.

(39) Sept. 23, 1885.—This is an excellent instance of the union of two cyclones, each well developed, the one from the west belonging to the class discussed under the first division of this paper, the other from the southwest belonging to those of the second division. The former moved eastward north of the Lakes

and the centre was about 200 miles north of Lake Ontario on the morning of Sept. 22d, with a central pressure of 29.4 inches. The latter came from the Gulf of Mexico; it had moved so slowly as it entered the country that disastrous rains had occurred for a succession of days. (At Galveston the unprecedented amount of 16.53 inches fell in six successive days.) On the morning of the 22d, the centre was off the North Carolina coast, with pressure 29.5 inches. The pressure diminished rapidly as the cyclone moved northeasterly about 75 miles from the coast. The former cyclone turned to the southeast near Quebec, its pressure remaining very nearly constant, and on the morning of the 23d the two centres united near Eastport, Maine, the combined storm having a central depression of 28.8 inches. After the union the storm continued in a northeasterly direction. In this instance the cyclone from the south was the more intense of the two as they neared New England, and seems not to have altered its path under the influence of the other but to have drawn the latter completely into its own control. The rainfall in this double storm was light in central New England, but the amounts were larger near the storm paths. Maximum areas exceeding two inches occurred at Nantucket, over which the second cyclone passed, and along the Maine coast where the depressions united; and an area exceeding one inch was located in northern Vermont nearest the path of the former cyclone. The times of beginning show a northerly progression about five hours in advance of the southern cyclone, and the times of ending a similar progression about five hours after its passage. There was also a later rain on the 23d in the northern states, after the cyclones had united. The rainfall was evidently due in the main to the southern cyclone.

(40) Feb. 12, 1886.—This was an extraordinary storm, both from the number of its secondary depressions and the consequent irregularity of its path, and also from the excessive rainfall which attended its passage near New England. As detailed in the *Monthly Weather Review*, it formed in the northwest and moved southeasterly to the Gulf of Mexico with the formation of several auxiliary depressions, making its central path

difficult to determine. It then moved northerly to the Lakes on Feb. 11th and 12th, with a central pressure 29.7 inches. A second development followed one day later along the eastern coast, with a central pressure also 29.7 inches. Moving more rapidly and curving to the northwest across Pennsylvania and western New York, it united with the other at Lake Ontario on the 13th. The combined storm with increasing energy moved down the St. Lawrence valley to the Gulf of St. Lawrence, beyond which it has not been traced, and was probably dissipated.

The rainfall in this storm has never been surpassed in any storm on record in Rhode Island, where the maximum area was located, and disastrous floods resulted in consequence. Its distribution was made the subject of special study, the results of which were published in *Science* No. 163 and reprinted as a supplement to the *Bulletin* of the N. E. Meteorological Society for February, 1886. From this article the following extracts are reproduced:

"The region covered by the greatest rainfall includes the states of Connecticut, Rhode Island and the eastern portion of Massachusetts. * * * * The special reports collected by the New England Meteorological Society, from one hundred and thirty-two observers, show that in a region covering more than one-half of Rhode Island, and the southeastern part of Connecticut, over *eight* inches of rain fell. The amount diminishes rapidly west and east of this region, about two and one-half inches having fallen on Cape Cod, and less than one inch in the northwestern part of Massachusetts. The region of heaviest rainfall is situated about four hundred miles northeast of the position of the centre of barometric depression [the second centre mentioned above,] on the afternoon of the 12th inst."

"The form of precipitation was almost wholly rain, a little snow or hail having occurred at its beginning at a few places only. The rainfall was nearly continuous for about two and one-half days, but was not of equal severity. Indeed, the greater part of the fall occurred in twenty-four hours, as is indicated by the following table, which contains the times of beginning and ending of the rain, the total amount, and the amount during a

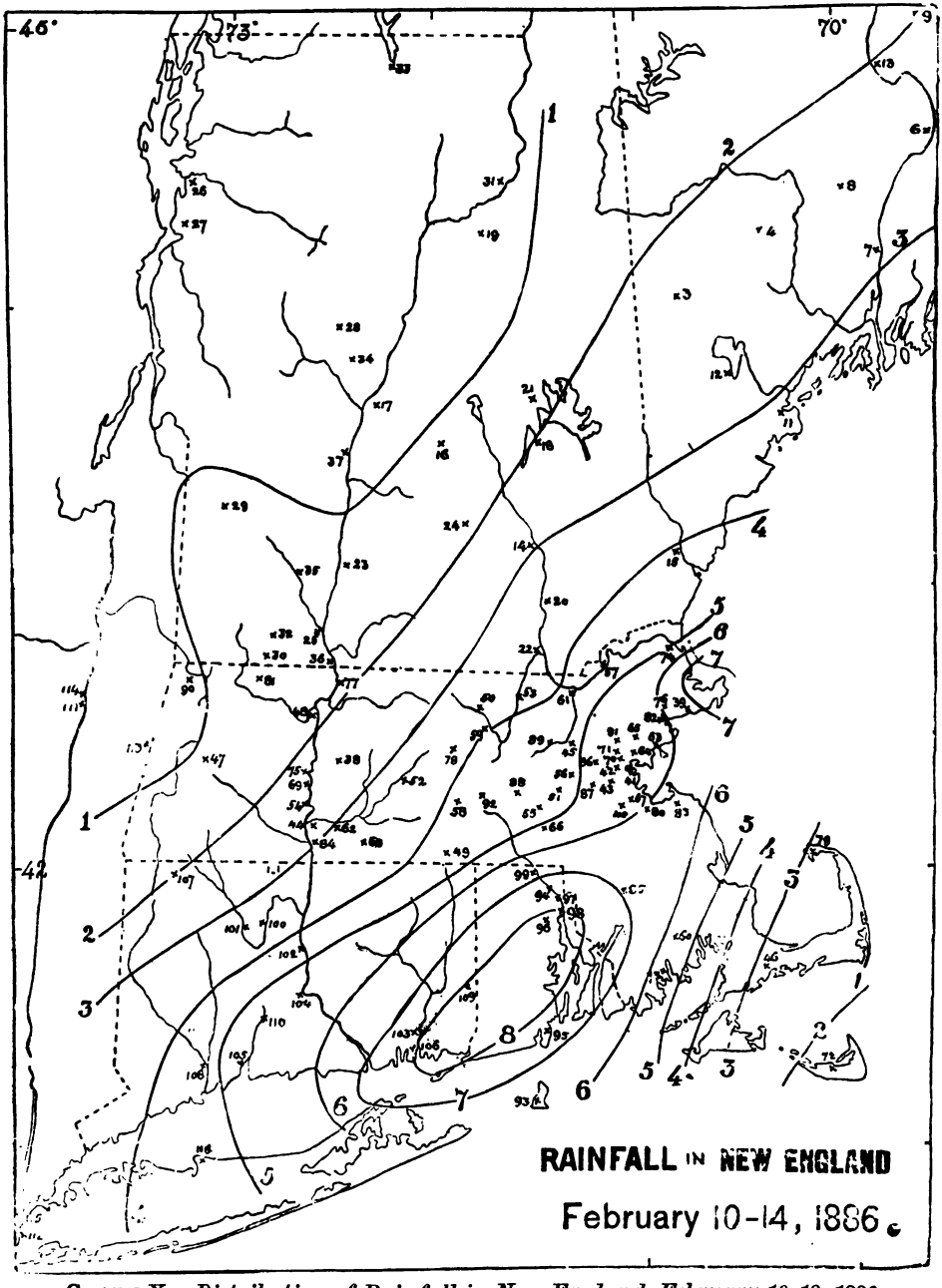

CHART X. *Distribution of Rainfall in New England, February 10–12, 1886.*

The small numbers indicate the position of the observing stations. The lines of equal rainfall are drawn at intervals of one inch.

specified interval of twenty-four hours. Similar records could be given from many other stations."

TABLE XII.

Times of beginning and ending of rain and interval of heaviest rainfall at selected stations, February 10-14, 1886.

Stations.	Time of Beginning.	Time of Ending.	Total Rainfall.	Interval of 24 Hours During Heaviest Rainfall.	Rainfall in 24 Hrs.
New York.....	10th, 10.30 A. M.	13th, Noon.	3.41	11th, 11.00 A. M.—12th, 11.00 A. M.	2.99
New London.	11th, 6.00 A. M.	13th, 4.20 P. M.	8 93	11th, 11.00 P. M.—12th, 11.00 P. M.	6 66
Providence ...	11th, 1.00 A. M.	13th, 11.30 P. M.	8.13	12th, 7.00 A. M.—13th, 7.00 A. M.	5.65
Boston.....	11th, 7.45 A. M.	13th, 2.45 P. M.	5.62	11th, 11.00 P. M.—12th, 11.00 P. M	4.45
Newburyport	10th, 5.30 P. M.	13th, 10.30 P. M.	4.78	11th, 9.00 P. M.—12th, 9.00 P. M.	3.30

It will be noted that the heaviest rains occurred at the time that the secondary centre was developing in the southern states, but that the region of greatest fall was far removed from the path of either centre. The pressure had been very high before the approach of these centres. On the morning of the 11th, "at Anticosti Island the barometer (reduced to sea-level) indicated 31.01 inches; in New England the pressure ranged from 30.9 inches on the eastern border to 30.6 on the western, while a trough of relatively low pressure, 30.0 inches, extended from the Gulf of Mexico to the Lake region. Light rains were falling along the eastern part of this trough in the central states, heavy rains upon the middle Atlantic coast, and the storm was just beginning in New England." As the storm-centre developed, the pressure fell rapidly; "between 7.00 A. M. of the 12th and 7.00 A. M. of the 13th, the fall was 0.54 inches at New York, 0.57 at New London, and 0.60 at Boston."

The accompanying map shows the distribution of the rainfall; the lines of equal rainfall are drawn at intervals of one inch; they are drawn freely, but represent fairly well the individual records. The small numbers on the maps are the numbers of the observing stations in the table containing the values of the rainfall, (which is not here reproduced.)

(41) March 22, 1886. This storm has been traced completely across the country from the Pacific coast eastward. It reached the Lakes on March 21st, as an elongated depression in which were two centres apparently well defined with pressure 29.1 inches. At the same time an auxiliary depression with pressure

29.3 inches formed in Delaware. The latter moved northeasterly close to the New England coast, while the former moved rapidly easterly, the two uniting on the Maine coast on the 22d, and proceeding northeasterly into the Atlantic. The precipitation was heavy, rain and snow mixed. Maximum areas exceeding two inches were in southeastern Massachusetts where the second cyclone passed, in southwestern Maine, a few miles south of the path of the first cyclone, and among the hills in southwestern Vermont and northwestern Massachusetts.

It will be seen from the foregoing description, that each of these storms is of especial interest and would merit close study. The examination of the precipitation records and the storm tracks, to which the present investigation is limited, seems to warrant the following conclusions, which are numbered in continuation of those of preceding divisions:

(13) In all cases where a secondary development was formed, it occurred on the *right* of the path of the primary cyclone; that is, on the south if the latter was moving easterly, (Nos. 37, 38, 41) and on the east if it was moving northerly or northeasterly. (Nos. 36, 40.)

(14) The precipitation was mainly due to the cyclone which approached from the south; that is the secondary cyclone in the above cases, and the cyclone which came from the Gulf of Mexico in No. 39.

(15) The maximum areas lie near the paths of the two cyclones, especially the southern. This accords with conclusion 10, given above in discussing the southern cyclones. A notable exception is No. 40, in which the maximum area was 300 miles east of the path of the secondary cyclone.*

(16) The precipitation was heavy in the region near which a cyclone was formed. This fact probably applies to other cyclones than those which are formed as auxiliary developments of those previously existing. It has already been mentioned in describing No. 29, as possibly indicating that the cyclone was formed near the coast.

* It has been conjectured that a secondary development formed on the southern coast of New England and moved northeasterly, but there is no evidence of this from the barometric records examined.

(17) The precipitation was also especially heavy in that region in which the union of the two centres occurred.

General Conclusion.—In the preceding discussion, care has been taken to avoid theoretical considerations and to confine the attention strictly to the results of observation. The conclusions drawn have therefore been wholly empirical, depending solely upon the particular storms examined, and liable to modification if other storms should be similarly discussed. The results obtained in each division have been collected at its close in a few distinct paragraphs, which might be taken as the final conclusion or the discussion without further comment. It may be well, however, by way of review, to present the most important of these results in a different form, thus summing up the whole investigation.

1. The distribution of the precipitation in the several storms is very irregular over New England, and each storm seems to be well-nigh individual in this respect. There are however, indications of certain common features in the storms discussed, which may be general features of all similar storms:

(1) The maximum area of precipitation in the northern group of cyclones which entered New England from the west, lies *south* of their path at an average distance of about 100 miles; in the corresponding southern group, it lies *north* of their path at an average distance of about 150 miles. (Table II, Concl. 2, 3.)

(2) The maximum area of precipitation in those cyclones which moved north of New England, lies about 300 miles south of their path, in central Massachusetts. This may be a secondary maximum of this group of cyclones. (Table II, Concl. 4.)

(3) The maximum area of precipitation in those cyclones which entered New England from the south, lies approximately along their path. (Table VI, Concl. 10.)

(4) Maximum areas of precipitation in cyclones which have a secondary development, or in combined cyclones, are found near the origin of the secondary development, along the path of each of the component cyclones and near the place of union. (Concl. 15, 16, 17.)

(5) The conclusions given under (1) above, possibly indicate

a topographical peculiarity, on account of which cyclones which enter New England from the west, deposit a greater amount of rain or snow in southern Vermont and New Hampshire and southwestern Maine. (Concl. 6.)

2. The amount of precipitation is greater in storms which enter New England from the south than from the west, in the proportion four to three. In double cyclones, it is greater in that component which comes from the south, which in cyclones having a secondary development is, in the cases examined, the secondary cyclone. (Concl. 9, 13, 14.)

3. The greater amount of precipitation precedes the passage of the cyclonic centres. The comparison of the distance of the centre when the precipitation began with its distance when the precipitation ceased, gives for the relative duration of the precipitation before and after the passage of the centre, the approximate proportion three to two for cyclones entering New England from the west, and two to one for those from the south. The ranges are however very large. (Tables II, VI.)

4. The direction in which the rain front and rear advance is not always the same as that of the centre of the cyclone. The deviation is more marked in those which enter New England from the west than in those from the south, especially in the summer when the rain is in connection with thunder-showers. The rate of movement is also markedly different. In the western group the rate is sometimes greater, sometimes less than that of the cyclone; in the southern group it is uniformly less. (Concl. 7, 8, 11, 12.)

PROVIDENCE, R. I., Oct. 6, 1886.